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# AN EVALUATION OF ELECTROPALATOGRAPHY IN THE TREATMENT OF DYSARTHRIA FOLLOWING PAEDIATRIC TRAUMATIC BRAIN INJURY: A CASE STUDY

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# ABSTRACT

Introduction: Dysarthria is a motor speech disorder commonly associated with Traumatic Brain Injury (TBI). TBI is a substantial cause of acquired brain injury in the paediatric population, with dysarthria being a common, and often persistent, consequence of such injuries, affecting a child's ability to participate fully in a variety of functional contexts. A current lack of literature studying the efficacy of using objective, instrumental techniques in the treatment of this client group forms the rationale for the present study.

Methods: A fifteen-year-old male subject who presented with dysarthria following a Traumatic Brain Injury (TBI) sustained four years prior to the present study, underwent electropalatography (EPG) treatment; an instrumental technique providing real-time visual bio-feedback on tongue to palate contact during speech. The subject's speech was systematically assessed in both the pre- and post- treatment conditions using standardised speech and oro-motor assessments, as well as qualitative and quantitative EPG assessment. Pre-treatment the subject presented with a mild dysarthria, characterised partly by imprecise consonants in the articulatory parameter of his speech. Three sounds were selected for intervention: /t/, /k/, and /s/. A therapy plan was administered using EPG as an instrumental tool in the treatment of the three sounds selected.

Results: Results of the post-treatment qualitative and quantitative EPG assessments noted some significant, though variable, changes in the spatial parameter of the subject's lingual-palatal contact for the three sounds treated. Post-treatment perceptual assessment did not demonstrate any increase in functional intelligibility, or any reduction in severity of the deviant speech characteristics noted in the articulatory parameter in the pre-treatment condition.

Conclusion: It was concluded that EPG was valuable in achieving changes in lingual-palatal contact patterns for the sounds treated, however these changes did not generalise into spontaneous connected speech. The initial presentation of the subject, theories of motor learning, and methodological limitations are discussed in relation to the findings.

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# 1.0 INTRODUCTION

Traumatic Brain Injury (TBI) is becoming a 'silent epidemic' with an estimated annual incidence of 200/100,000 (Wechsler et al. 2005). Brain Injury is the most common cause of fatality and sustained disability in children and teenagers (Guyer & Ellers, 1990), with vehicular accidents accounting for the majority of cases. A significant number of children (5.6/100, 000) are admitted to intensive care units with TBI in the United Kingdom annually (Parslow et al., 2005).

By definition TBI is an insult to the brain, most commonly as a consequence of a closed head injury (Murdoch & Theodoros, 2001). Closed head injury often leads to diffuse damage of the white axonal matter of the brain (DAI), and secondary diffuse and/or focal damage, for example oedema, haemorrhage, contusions and ischaemia (Murdoch & Theodoros, 2001). Improved scanning and medical intervention procedures for individuals post-brain injury have led to increasing rates of survival in recent decades, necessitating further research into outcome and long term rehabilitation efficacy for this growing client group (Cahill et al. 2001).

Such diffuse and varied injury to the brain results in a neurologically and behaviourally heterogeneous client group. Common sequelae include physical disability encompassing motor speech disorders; and cognitive deficits such as language and memory; (Hanten et al. 2004, Catroppa & Anderson, 2004, Moran & Gillon, 2004); attention (Yeates et al. 2005, Robin et al. 1999); and executive function (Levin & Hanten, 2005).

Dysarthria is a motor speech disorder commonly associated with TBI in childhood (Costeff et al. 1990), and can impact on a child's life academically and socially at the ICF levels of impairment, activity and participation (WHO, 2001). Speech has been identified as 'vital to a wide range of vocations, and it is the means to various social and recreational pleasures', (Kent, 2000:396), therefore communication outcomes of TBI are considered fundamental in determining quality of life following rehabilitation (Najenson et al. 1978).

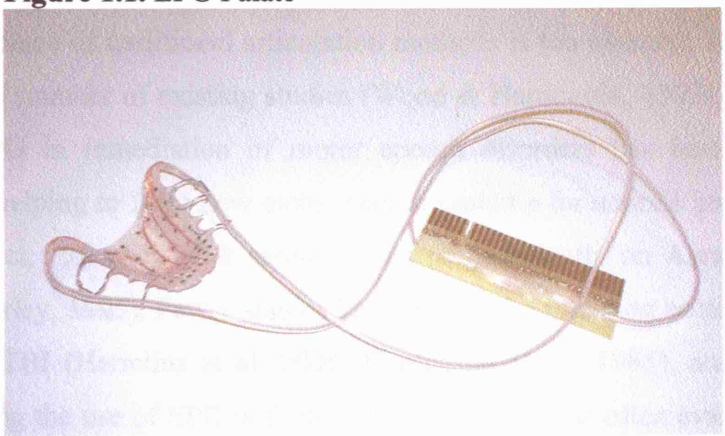
Popular current classification and rating of dysarthria was conceptualised by Darley, Aronson and Brown some decades ago, based on perceptual analysis of the various presentations of the disorder, and hypotheses were formed as to the neurological aetiology of each sub-type (Darley et al. 1969a, 1969b, 1975). Dysarthria can be defined from other motor speech disorders as, 'a collective name for a group of neurologic speech disorders resulting from abnormalities in the strength, speed, range, steadiness, tone, or accuracy of movements required for control of the respiratory, phonatory, resonatory, articulatory, and prosodic aspects of speech production. The responsible pathophysiologic disturbances are due to central or peripheral nervous system abnormalities and most often reflect weakness; spasticity; incoordination; involuntary movements; or excessive, reduced, or variable muscle tone.' (Duffy, 2005:5).

Dysarthria is a more persistent sequela of TBI than co-occurring deficits such as aphasia, (Costeff et al, 1985), and the articulatory parameter has been identified as the most commonly occurring communicative consequence of TBI in children, second only to dysgraphia, (Hécaen, 1976). Cahill et al. (2001) studied a group of 22 paediatric subjects following TBI. They found that compared with controls, the subjects were perceptually less intelligible at both the single word and sentence level. A speech sample analysis demonstrated that 59% of the subjects were rated as producing imprecise consonants, making this the most frequently occurring deviant speech parameter. Subsequent objective measurements were taken in the articulatory parameter of the participants' speech using electropalatography (EPG); electromagnetic articulography (EMA); and tongue and lip pressure transducer systems. These assessments concluded that tongue elevation was often impaired, as well as the rate at which the tongue was able to move in order to articulate speech sounds. Stierwalt et al. (1996) found similar objective instrumental assessment outcomes to be associated with overall perceptual judgements of articulatory performance. Such articulation impairments greatly affect intelligibility of speech (Robertson & Thompson, 1986), with eight percent of adolescents having no intelligible speech in the long term following TBI, (Ylvisaker, 1986). This makes children with acquired dysarthria following TBI a prevalent and important client group to assess and manage; particularly those with impaired tongue function leading to reduced intelligibility. It has been found that dysarthria acquired during development does not share the same features as dysarthria acquired in adulthood (van Mourik et al., 1997), which supports the notion that conclusions drawn from related adult studies cannot be inferred to the developmental population.

The traditional approach to assessing articulation of speech is a largely auditory-based one, whereby the tester transcribes speech output phonetically using an extended set of symbols for disordered speech (Duckworth et al. 1990). The disadvantages in using such a system to transcribe atypical speech with non-categorical errors, in particular dysarthria, are multiple. Firstly, this approach is subjective, relying on the perception and experience of the clinician, and possibly leaving some common features of dysarthria unidentified such as distortions, co-articulations, and abnormal movements in the transition from one sound to another (Wood & Hardcastle, 1999). In addition there is a tendency towards poor inter-rater reliability when using these more traditional, subjective methods in the assessment of dysarthric speech (Wood & Hardcastle, 1999). However despite these significant findings, there is a lack of literature addressing the use of emerging physiologic approaches in the assessment and management of dysarthria in children following TBI.

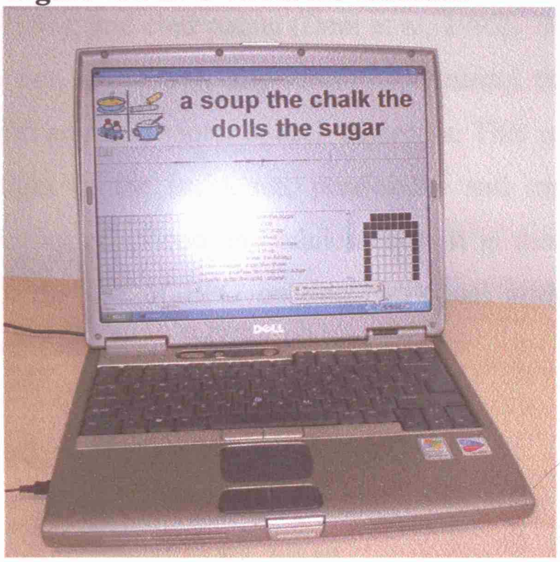
Consonant imprecision has been identified as existing in 95% of clients presenting with TBI (Theodoros et al, 1994), and advances in physiological measures of assessment provide an opportunity to assess these features more consistently, precisely and objectively (Kent, 2000). In particular, the electropalatograph (EPG) (Hardcastle et al. 1991) has been identified as a relatively cheap, non-invasive and objective instrumental technique for use in assessing articulation (Stone, 1996). EPG consists of an artificial palate anchored to the teeth. The palate contains 62 touch-sensitive electrodes that run from the alveolar ridge back to the junction between the hard palate and the velum (Figure 1.1).

**Figure 1.1.** EPG Palate



The accompanying data capture and analysis system allows measurement of the timing and placement of tongue to palate contacts every 10 milliseconds, providing a moving visual representation on a computer screen of these articulatory dynamics in continuous speech. The stimuli are provided at the top of the screen with the moving visual feedback appearing on the bottom right of the screen (Figure 1.2). A microphone is attached to the main unit to record acoustic data simultaneously thereby providing both acoustic and physiological data for precise and detailed analysis.

**Figure 1.2.** EPG visual bio-feedback




An advantage of the visual representation is the opportunity to use EPG as a tool for intervention as it provides unique visual biofeedback useful in populations for whom the language of traditional articulation methods is too abstract. A review of the relatively small number of existing studies (Wood & Hardcastle, 1999) concludes that the use of EPG in remediation of motor speech disorders has been found to be efficacious in helping to form new motor speech patterns for sounds involving tongue to palate contact. However adult studies focus predominantly on Apraxia of Speech (Howard & Varley, 1995). Fewer studies have focussed on treating acquired dysarthria as a result of TBI (Hartelius et al. 2005, Hardcastle et al., 1985), and of the small number studying the use of EPG with this client group, this is often evaluating the use of EPG as an assessment and speech profiling tool, (Goozée et al. 1999), with a mention of implications that may inform future intervention studies (Cheng et al. 2005). Hartelius et al (2005) conducted an EPG intervention case study of an adult male presenting with dysarthria following TBI. They found that the EPG technique was effective in creating a perceptual contrast for the participant's productions of /s/ and /t/, resulting in an increase in the perceptual intelligibility of the subject's output in spontaneous, connected speech. However the results of such an adult-focussed study cannot be generalised to a paediatric population with acquired dysarthria as a result of TBI, and while a handful of paediatric studies have found EPG to be an effective treatment tool, these studies have mostly focussed on developmental neurological conditions such as Worster-Drought Syndrome (Morgan-Barry, 1995); phonological disorders (Dagenais, 1994); and cleft palate (Dent et al, 1992). To the present author's knowledge there are not, at current, any studies measuring the outcomes of EPG therapy in children with acquired motor speech disorders. This represents a large void in the literature in light of the incidence, persistence and unique presentation of dysarthria acquired during childhood and adolescence. It is therefore the aim of the current study to pilot the use of EPG on one individual with acquired childhood dysarthria as a result of TBI.

The present study will address three specific aims:

## 1.1 AIMS

### 1.1.1. Perceptual

To determine whether there are perceptual improvements made in speech following the treatment. It is hypothesised that a change in articulatory parameters will be observed.

### 1.1.2. Spatial

To determine whether there are changes in spatial tongue to palate placement in three sounds: /t/, /k/, and /s/. It is hypothesised that the subject will achieve more appropriate tongue to palate placement following treatment.

### 1.1.3. Timing

To determine whether there is a reduction in timing following the treatment for each of the three sounds. It is hypothesised that a reduction in timing will be observed through practice effects.

# 2.0 METHOD

## 2.1 PARTICIPANT

### 2.1.1. Inclusion Criteria

The participant was required to have received a diagnosis of either a moderate (Glasgow Coma Scale (GCS) 8-12) or severe (GCS <8) TBI on admission, and be greater than twelve months post onset. The participant was required to speak English as their first language in order to make valid use of the standardised assessments and EPG treatment procedures, both based on the English Language. The participant was required to have a diagnosis of perceptible dysarthria as judged by a qualified Speech and Language Therapist (SLT), and to present with a cognitive level of at least eight years in order to gain maximum benefit from the feedback provided by the EPG system.

### 2.1.2. Exclusion Criteria

Participants with dental braces were excluded as they are not compatible with the EPG palate. Participants were excluded on the basis of a co-existing neurological disease or disorder, or speech disorder, sustained either developmentally, or through an acquired cause other than their TBI.

### 2.1.3. History of Presenting Condition

The subject (AB) was fifteen years of age at the time of the present investigation. AB had sustained a severe (4/15 on Glasgow Coma Scale at admission) TBI at the age of 11 years subsequent to being hit by a motor vehicle whilst riding a bicycle. AB sustained a skull fracture and broken clavicle. A CT scan showed subsequent neurological damage to be generalised oedema with a left frontal contusion and left orbitofrontal fracture to the skull. AB was tracheostomised, ventilated and fed nasogastrically in intensive care for three weeks. AB then spent a further three months as an inpatient before being transferred to a paediatric rehabilitation centre for ten months. AB was anarthric subsequent immediately following the accident but began to use single words after three months where his speech was then characterised by severe dysarthria. His speech increased to sentences and phrases over the following months. No specific speech treatment for dysarthria was administered during the participant's inpatient rehabilitation stay, nor in the community or school following discharge.

At the time of the study AB had difficulties with gait and a right-sided tremor affecting his right hand, clinically indicating a persistent motor impairment following the left-hemisphere brain lesion. AB was found to have a full Intelligence Quotient of 108 (Percentile Rank: 70, 95% Confidence Interval: 101-114) based on The Weschler Abbreviated Scale of Intelligence (WASI) (Weschler, 1999) demonstrating his appropriateness for the EPG treatment approach.

#### 2.1.4. Medical History

Prior to his accident AB had developed within normal limits. He was born at full term with no complications and met milestones throughout his development. He began to acquire speech early in relation to a typical developmental trajectory, at the age of eight months. AB had no previous hospitalisations or significant medical history besides mild childhood asthma which had resolved previously.

## 2.2 PROCEDURE

### 2.2.1. Assessment

#### *2.2.1.1. Perceptual Speech Assessment*

The following baseline assessments were administered in order to: 1) primarily measure treatment outcome, and 2) characterise AB's dysarthria.

*2.2.1.1.1 Goldman-Fristoe Test of Articulation-2 (Goldman & Fristoe, 2000)*

The GFTA-2 is a standardised assessment that uses pictures to elicit and assess the production of thirty-nine consonants and consonant clusters in order to profile a participant's phonetic inventory.

*2.2.1.1.2 Verbal Motor Production Assessment for Children (Hayden & Square, 1999)*

This test is reported to evaluate the integrity of the neurological motor speech system through testing children's motor movements, in addition to speech sounds. The assessment measures five main parameters. The first is Global Motor Control which assesses tone, respiration, phonation, reflexes, and vegetative functions of chewing and swallowing. Focal Oro-Motor Control assesses the volitional movement of the mandible, lips and face, and tongue both in isolation and in combination. Speech movements are then assessed both in isolation and in combination. The Sequencing section examines speech and non-speech sequences of movements. The Connected Speech and Language Control section required the subject to formulate a narrative using four pictures in order to observe the control of oro-motor movements in connected speech. Speech Characteristics then evaluates the pitch, resonance, intonation, volume, and phonation of the subject's output throughout the assessment.

*2.2.1.1.3. Children's Speech Intelligibility Measure (Wilcox & Morris, 1999)*

This test requires the participant to read aloud a list of fifty words which are audio-recorded. The recording is then listened to by a rater who must not be familiar with the participant's speech. Twelve multiple-choice options for each word are given to the rater for selection and the total raw score is then converted into a percentage of intelligibility.

*2.2.1.1.4. Perceptual Dysarthria Rating*

A speech sample was elicited from AB using 'The Grandfather Passage' (Duffy, 2005). This was rated perceptually using the 'Form for rating deviant speech characteristics associated with dysarthria' (Duffy, 2005) which measures dysarthric speech characteristics based on a severity scale of 0 (normal) to 3 (severely deviant).

*2.2.1.2. Instrumental Electropalatography Speech Assessment*

The Reading Electropalatograph-3 (EPG) was used to gain an objective motor speech profile both pre and post treatment. This involved AB reading a word list containing a variety of consonants in both word initial and final positions (Appendix A) with the EPG palate in-situ.

Each word was recorded five times in order to gain a representative sample of speech production given findings of individual variation noted on EPG (McAuliffe et al., 2003), and to allow analysis of the variability of AB's production. Each word was also preceded by the determiner 'a' to ensure a consistent vowel environment and tongue position prior to producing each word, e.g., 'a tart'; 'a tart'; 'a tart'; etc. Spatial and timing baseline measures of the data were then taken in order to prioritise sounds to be targeted in therapy and to measure their outcome.

The following three spatial measures and four timing measures were taken in both the pre and post therapy conditions.

*2.2.1.2.1 Spatial parameters*

Three spatial measures were calculated:

*2.2.1.2.1.1 Frame of maximum contact.* The first measure was the frame of maximum contact of the tongue against the palate for each consonant (Byrd et al. 1995). The frame in which the tongue first made contact with the highest number of electrodes was recorded as the most representative individual frame of its production pattern (Appendix B), enabling a comparison of the production patterns pre- and post-treatment.

*2.2.1.2.1.2. Variability index.* The frames of maximum contact were then used to calculate the variability index for each consonant word initially and finally both before and after treatment (Appendix C), (Gibbon et al. 2003). This gave a measure of the level of variability of tongue placement for each sound. The variability index was measured by calculating the number of times each of the sixty-two electrodes was contacted over five productions of each phoneme, in each word position (Appendix D). In each set of five productions a score of zero was recorded for those electrodes contacted on every occasion, or on no occasion therefore indicating maximum stability and minimum variability. A higher score was recorded for those electrodes contacted only some of the time, fifty being the maximum score for each electrode, therefore representing a less stable, and more variable production over five repetitions.

*2.2.1.2.1.3 Centre of Gravity index.* The centre of gravity (COG) scores (Gibbon et al. 2003) were then calculated for each consonant in each word position to study patterns of fronting or backing across the palate for each phoneme (Appendix E), and to compare this before and after treatment. The formula used to calculate the COG values is shown in Appendix F. The COG values were calculated for each production and the mean average of five productions was recorded for each phoneme in each word position, both before and after treatment. The numerical COG value was used to indicate overall anterior-posterior position of the tongue against the palate for that phoneme. Low values represented the posterior region of the palate and increased in value towards the central and anterior rows of the palate.

*2.2.1.2.2. Timing parameters*

The average duration across three phases of tongue-to-palate movement was calculated (McAuliffe et al. 2003) for each sound in each position (Appendix G). Four measurements were taken for each individual phoneme production across the three phases in order to calculate the total phoneme duration:

*2.2.1.2.2.1. Approach phase.* The first measure was taken as the number of contacted electrodes started to increase as the tongue began to move into position against the palate for the consonant.

*2.2.1.2.2.2. Constriction/Closure phase.* The second measure was taken once a complete row of electrodes was contacted from left to right, thus forming a complete seal in the oral cavity. The formation of this seal was the point at which the approach phase ended and the constriction phase began, and this lasted until the seal of electrodes was broken to release the air built up behind the constriction, this being the third time measurement taken.

*2.2.1.2.2.3. Release Phase.* The release phase then began from this measurement, and continued until the fourth measurement at the point when the number of contacted electrodes ceased to decrease steadily as the tongue moved away from the palate. In the case of the voiceless alveolar fricative /s/ which did not require a complete seal, the constriction phase was calculated from when the tongue was touching 10% fewer electrodes than in the maximum frame of contact, through the frame of maximum contact to the point where it touched 10% fewer electrodes than the maximum as the contact decreased.

### 2.2.2. Treatment

Of the three sounds selected for treatment in both word initial and word final positions (/t/, /k/ and /s/) guidelines for standard production of the consonants were obtained (Ladefoged, 1993) in order to create a target production of each consonant for therapy. These models were produced by the SLT using the EPG-3 system and saved to be loaded as a visual model for AB during the therapy process. A thirty minute, weekly session of therapy was provided for ten weeks. The therapy plan (Appendix H) moved through specific objectives which were to be met at each stage before moving onto the next. The criteria for meeting each stage was set at 100% for example 5/5 or 10/10 correct.

#### *2.2.2.1. Demonstration phase*

The first stage of treatment was the demonstration phase whereby the clinician familiarised AB with the terminology used, and taught AB to practice monitoring his own errors using visual feedback when producing silent placement postures (i.e. no voicing of sounds at this stage) according to the loaded models produced by the therapist. AB was required to use the terminology 'front' 'back' or 'middle' to describe where the therapist placed her tongue using the visual feedback given on the screen. In order to develop his own kinaesthetic awareness AB was then required to place his own tongue against the palate according to instructions using the same terminology. AB's baseline assessment productions were then loaded on the left of the screen which he was required to compare to the therapist's model patterns loaded on the right of the screen. He was then asked to describe how they differ using the placement terminology described along with identifying 'gaps' in his own productions where the therapist's production had a complete line of blocked squares. This aimed to facilitate AB's understanding of why particular sounds were being targeted in the treatment.

*2.2.2.2. Silent lingual-palatal posturing phase*

In the lingual-palatal posturing phase each task was carried out with the palate in-situ using the moving visual feedback provided by the screen and the therapist's static model. This was then followed by the same task without the use of visual feedback, as assessed by the therapist viewing the screen, and finally without the palate in-situ in order to facilitate generalisation of the postures. These productions were assessed perceptually by the therapist. The production phase began with AB producing silent patterns for each sound and holding each posture for three seconds. The next aim was for AB to be able to alternate between two silent lingual-palatal postures e.g. /t/ /k/, holding each for two seconds.

*2.2.2.3. Manner and voicing contrasts phase*

Manner of articulation and voicing contrasts were approached using a similar process as placement with a focus initially on terminology and discrimination and then progressing to production. The terminology used was 'stopping' for plosives, 'blowing' for fricatives, and 'buzz/ no buzz' for voiced and voiceless sounds.

*2.2.2.4. Syllable sequence production phase*

Following this stage AB moved through producing each consonant in a variety of consonant+vowel (CV) syllable sequences to stabilise the production of each consonant in different phonetic environments. Each consonant /t k s/ in turn was produced in CV sequence with the following short and long vowels: /ɪ æ e ɒ ʌ ɑ ɛ ɔ u/. This was carried out with visual feedback, without visual feedback, and then without the palate in-situ, and each to a rate of 100% correct. The same process then followed using the same consonants and vowels but in vowel+consonant (VC) structures to ensure the motor program was stabilised in different phonetic environments.

#### *2.2.2.5. Single word, and phrase production phase*

Single words were then used following the same principles and process of therapy. The words were of a CVC structure with the consonants differing in place and manner in order to alternate between the two opposing postures. The words also contained different vowel combinations, thus further stabilising AB's motor production of the targets in different phonetic environments. Finally the single words were put into phrases also containing the target postures i.e. 'I saw/take/cook the ....'. This aimed to further stabilise AB's productions whilst facilitating generalisation through using functional phrases.

### 2.2.3. Data Analysis

#### *2.2.3.1. Perceptual*

The perceptual speech assessments, outlined above in section 2.2.1.1., were re-administered following therapy. The assessment scores were then qualitatively compared in order to assess if changes were made in any of these areas following treatment.

#### *2.2.3.2. Spatial*

The pre- and post-treatment spatial assessment data, outlined above in section 2.2.1.2.1, was analysed using the Wilcoxon Signed Rank Test. This was the statistical test most appropriate for use with a small sample of within-subject data to determine whether any post therapy changes were of statistical significance. A qualitative phonetic placement analysis was also carried out which visually compared frames of maximum contact both before and after treatment.

*2.2.3.3. Timing*

The timing assessment data, outlined above in section 2.2.1.2.2., taken in both the pre- and post- therapy conditions was also analysed using the Wilcoxon Signed Rank Test to find if any post therapy changes were of statistical significance.

# 3.0 RESULTS

## 3.1 PERCEPTUAL

### 3.1.1. Goldman-Fristoe Test of Articulation-2

Before treatment AB's phonetic inventory was found to be that expected of a fully developed adult sound system using the GFTA-2. This was with the exception of the presence of word final /l/ vocalisation which is characteristic of AB's local dialect, i.e. *Estuary English* (Wells, 1997).

### 3.1.2. Verbal Motor Production Assessment for Children

In the pre-treatment condition AB scored the following on each subtest: Global Motor Control: 10/20 (50%), Focal Oro-motor Control: 184/268 (68.66%), Sequencing: 45/46 (97.83%), Connected Speech and Language Control: 39/45 (86.67%), and Speech Characteristics: 3/7 (42.86%). In the post-treatment condition AB obtained the same scores for the latter three subtests. In contrast to the pre-treatment condition he scored the following on the remaining two subtests: Global Motor Control: 15/20 (75%), and Focal Oro-Motor Control: 204/268 (76.12%).

### 3.1.3. Children's Speech Intelligibility Measure

In the pre-treatment condition AB's Intelligibility was found to be 96%. The score remained at 96% when the test was re-administered in the post-treatment condition.

### 3.1.4. Perceptual Dysarthria Rating

The severity scores for each of the perceptual speech parameters commonly associated with dysarthria, (Duffy, 2005) in both treatment conditions are shown below in Table 3.1. Intra-rater reliability data was obtained within three months of the initial scoring. The intra-rater reliability data was found to be 68.2% in agreement on presence or non-presence of a feature, with 59.1% agreement on the severity rating of the feature.

**Table 3.1.** Pre- and post-treatment perceptual speech parameters as rated on the 'Form for Rating Deviant Speech Characteristics Associated with Dysarthria', (Duffy, 2005:90)

| Speech parameter | Feature | Pre-treatment | Post-treatment |
|---|---|---|---|
| Pitch | Pitch level | Normal | Normal |
| | Pitch breaks | Mild | Normal |
| | Monopitch | Mild | Mild |
| | Voice Tremor | Mild | Moderate |
| | Myoclonus | Normal | Normal |
| | Diplophonia | Normal | Normal |
| Loudness | Monoloudness | Mild | Mild |
| | Excess loudness variation | Mild | Normal |
| | Loudness decay | Mild | Normal |
| | Alternating loudness | Normal | Normal |
| | Overall loudness (+/-) | Mildly reduced | Normal |
| Voice quality | Harsh voice | Moderate | Severe |
| | Hoarse (wet) | Normal | Normal |
| | Breathy (continuous) | Normal | Normal |
| | Breathy (transient) | Normal | Normal |
| | Strained voice | Mild | Moderate |
| | Voice stoppages | Normal | Normal |

| | | | |
|---|---|---|---|
| | Flutter | Normal | Normal |
| Resonance and intra-oral pressure | Hypernasality | Moderate | Moderate |
| | Hyponasality | Normal | Normal |
| | Nasal emission | Normal | Normal |
| | Weak pressure consonants | Normal | Normal |
| Respiration | Forced inspiration-expiration | Mild | Mild |
| | Audible inspiration | Normal | Normal |
| | Inhalatory stridor | Normal | Normal |
| | Grunt at the end of expiration | Mild | Mild |
| Prosody | Rate | Moderately reduced | Mild |
| | Short phrases | Moderate | Mild |
| | Increased rate in segments | Normal | Normal |
| | Increased rate overall | Normal | Normal |
| | Reduced stress | Moderate | Mild |
| | Variable rate | Mild | Mild |
| | Prolonged intervals | Moderate | Mild |
| | Inappropriate silences | Mild | Normal |
| | Short rushes of speech | Normal | Normal |
| | Excess and equal stress | Normal | Normal |
| Articulation | Imprecise consonants | Mild | Mild |

| | | | |
|---|---|---|---|
| | Prolonged phonemes | Moderate | Mild |
| | Repeated phonemes | Normal | Normal |
| | Irregular articulatory breakdowns | Mild | Mild |
| | Distorted vowels | Mild | Normal |
| Other | Slow AMRs | Moderate | Moderate |

On pre-treatment assessment AB's speech was characterised by features associated with a spastic type dysarthria (Duffy, 2005). The assessment data in Table 3.1 illustrates the presence of these features, with a moderate score in the parameters of pitch, loudness, voice quality, resonance, prosody and articulation. The most perceptually salient features of AB's speech were voice tremor; monoloudness; a harsh, strained, breathy voice quality; hypernasality; reduced rate; short phrases; reduced stress; prolonged intervals; equal and excess stress; imprecise consonants; prolonged phonemes; and slow AMRs. These features, with the exception of voice tremor, and prolonged phonemes and intervals, contribute to the clusters of abnormal speech characteristics associated with spastic dysarthria i.e. Prosodic Excess; Articulatory-Resonatory Incompetence; Prosodic Insufficiency; and Phonatory Stenosis, (Duffy, 2005).

Overall, qualitative examination of the data post-treatment indicated some improvements in AB's prosodic speech features. However apart from an improvement in the severity of AB's prolonged phonemes post-treatment, few other changes were noted in the parameter of articulation. This was the feature of AB's speech hypothesised to be most responsive to EPG treatment.

Intra-rater reliability data was obtained within three months of the initial scoring. Analysis of the reliability data found the scores to be 68.2% in agreement on presence or non-presence of a feature, with 59.1% agreement on the severity rating of the feature.

## 3.2 SPATIAL PARAMETERS

### 3.2.1. Quantitative Analysis

#### *3.2.1.1 Centre of Gravity (COG)*

The mean average COG scores for each sound in each word position are detailed in Appendix E. Figure 3.1 below illustrates mean average COG scores for each sound in both word positions and in both treatment conditions.

**Figure 3.1**. COG scores for phonemes pre- and post- treatment

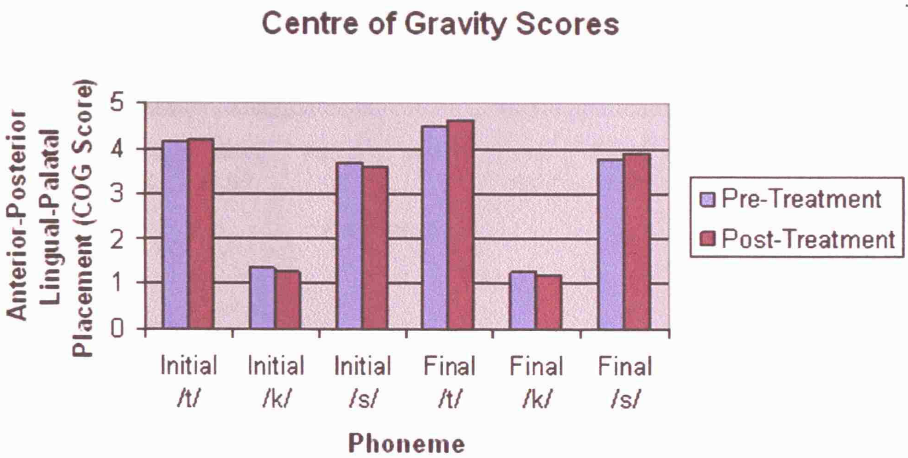
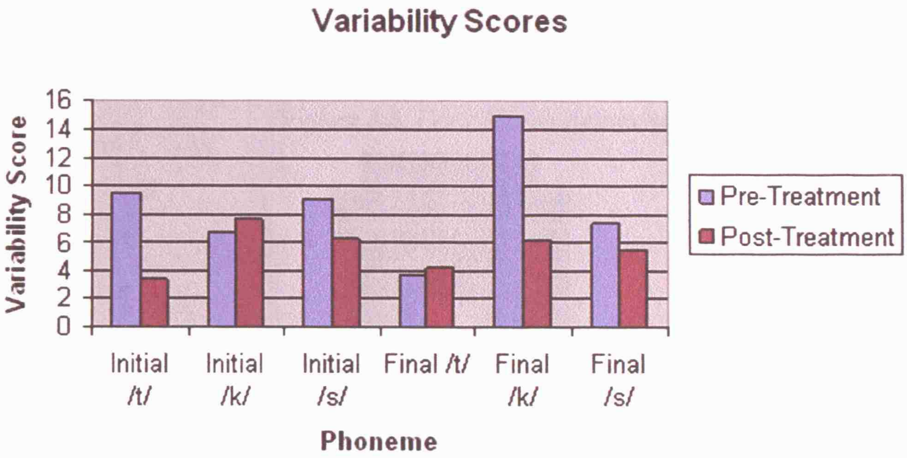



Figure 3.1 demonstrates that /t/ had a more anterior placement, both word initially and finally, following treatment. The same was found for /s/ in word initial position, in contrast to the productions of word final /s/ which were produced in a more posterior position overall. The tongue to palate contact for /k/ is shown to be more posterior in the post treatment condition both in word initial and word final position.

*3.2.1.2. Variability*

Appendix C gives the variability score for each sound in each condition based on ten productions of each sound in each position. Figure 3.2 below illustrates variability scores for each sound in both word positions, and in both treatment conditions.

**Figure 3.2.** Mean variability scores for phonemes pre- and post- treatment.



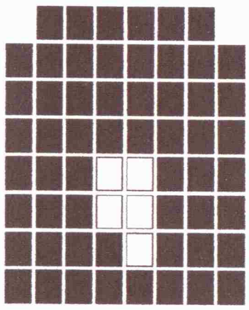

It can be seen in Figure 3.2 that in the post treatment condition variability decreased for all phonemes with the exception of initial /k/ and final /t/. The Wilcoxon Signed Rank Test found the overall variability scores not to be statistically significant at the 0.05 level of significance, based on a one-tailed hypothesis ($W=3$, $p=0.058$). For those sounds which did show reduced variability the Wilcoxon Signed Rank Test found the overall reduction to be statistically significant at the 0.05 level of significance, based on a one-tailed hypothesis ($W=0$, $p=0.034$).

3.2.2. Qualitative Analysis

The frames of maximum contact for each sound in each position both before and after treatment are provided in Appendix B. The numbers of contacted electrodes in each of these frames were used in order to calculate the quantitative spatial data but were also used to qualitatively analyse the data for spatial changes which occurred following treatment.

In the qualitative analysis EPG was found to be beneficial in identifying motor control features which were not documented during the perceptual assessment. For example AB often produced double articulations whereby the tip/blade and the base of the tongue contacted the anterior and posterior regions of the palate simultaneously when producing /t/ (Figure 3.3). This objective qualitative analysis has been documented as an advantage to using EPG in previous paediatric treatment studies (Gibbon & Wood, 2002).

**Figure 3.3**. Double articulation in production of /t/



In a comparison of pre- and post- treatment frames of maximum contact certain changes in articulation patterns were observed. The frames of maximum contact for initial /t/ before and after treatment are detailed in figures 3.4 and 3.5 respectively. These figures illustrate that lingual closure across the palate occurred at row three on four out of the five productions pre-treatment (Figure 3.4). Post-treatment however, AB's lingual-palatal contact was more anterior with complete closure occurring consistently back to row two only for all of the five productions (Figures 3.5). This qualitative finding highlights the quantitative COG and variability analyses, detailed in sections *3.2.1.1 and 3.2.1.2.*, which noted that initial /t/ was produced more anteriorly and consistently following EPG treatment.

**Figure 3.4.** EPG frames of initial /t/ pre-treatment

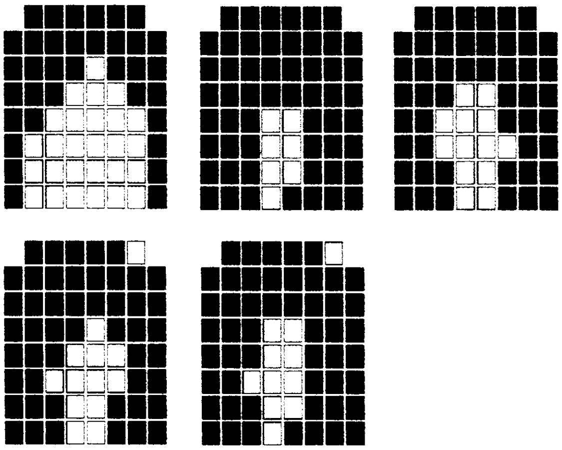
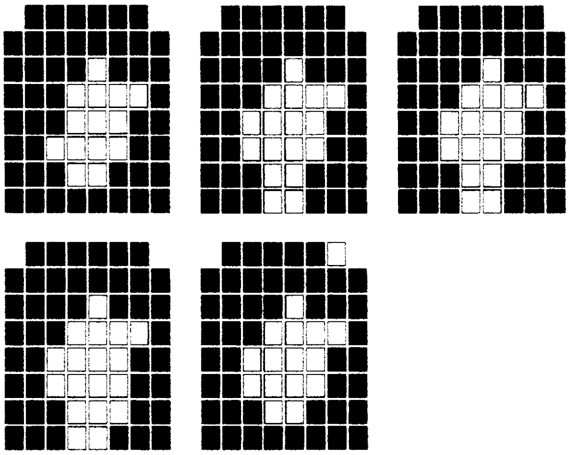


**Figure 3.5.** EPG frames of initial /t/ post-treatment



Variability and COG scores for final /s/ productions were also illustrated by qualitative analysis of the frames of maximum contact. Post-treatment it is shown in Figure 3.7 that the lingual grooving, the area of maximum constriction which produces fricative turbulence, was more anterior than in the pre-treatment condition (Figure 3.6). Following treatment the lateral lingual-palatal contact was more anterior and more consistent. Figure 3.7 demonstrates a gap no wider than four electrodes around the alveolar ridge in the post-treatment productions. This gap was observed to be wider in the pre-treatment assessment (Figure 3.6) with a gap of up to eight electrodes in row two in the alveolar region.

**Figure 3.6.** EPG frames of final /s/ pre-treatment.

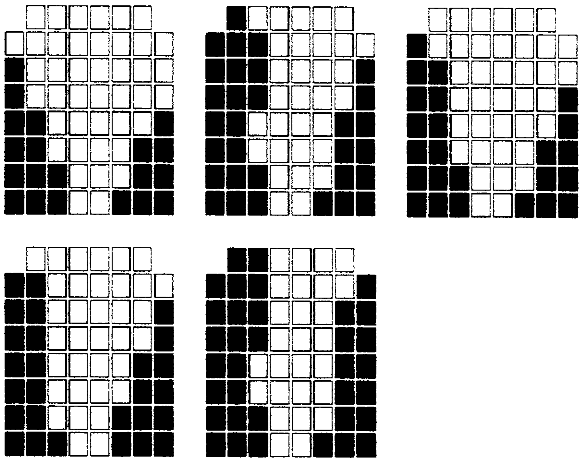
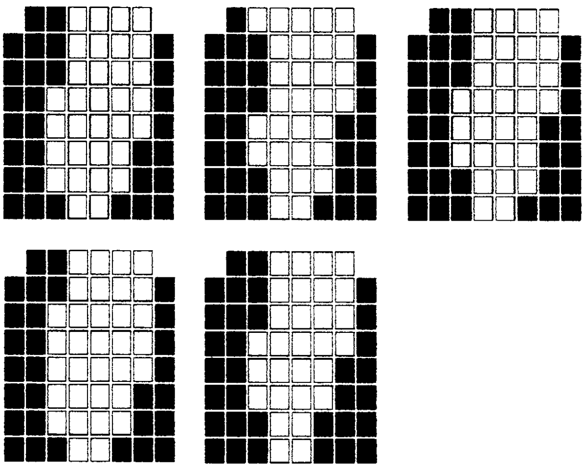


**Figure 3.7.** EPG frames of final /s/ post-treatment.

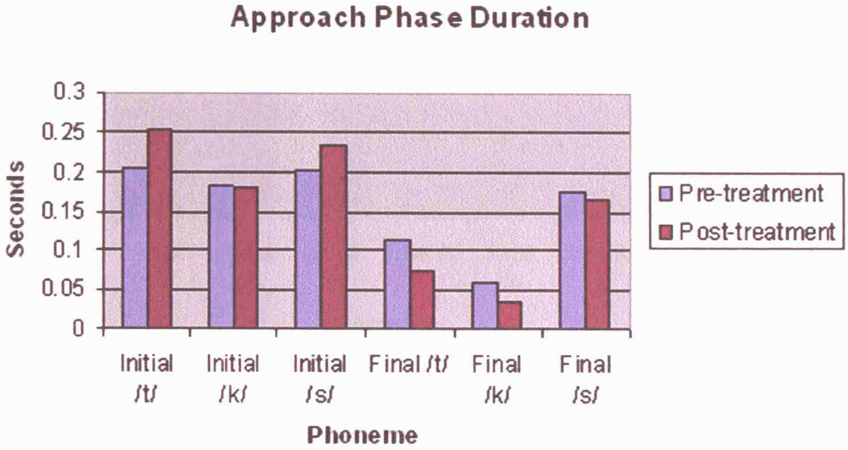


## 3.3 TIMING PARAMETERS

### 3.3.1. Approach Phase

Mean average approach phase times are shown in Appendix G for each phoneme in each position, in both conditions. Figure 3.8 illustrates the mean length of the approach phases for each phoneme, in each position, both before and after treatment.

**Figure 3.8.** Mean approach phase durations pre and post-treatment.

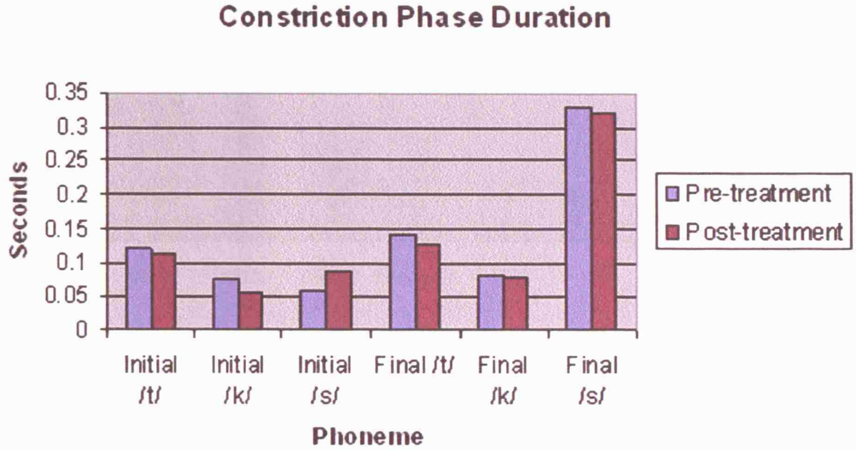



No time reduction in approach phase was found for /t/ in initial word position following treatment. In the word final position the approach phase for /t/ was significantly reduced in the post-treatment condition according to the Wilcoxon Signed Rank Test based on a unidirectional hypothesis at the 0.01 level of significance (W=1, p= 0.006). Following treatment a reduction in the approach phase was found for /k/ in both the word initial and final positions. Neither of these reductions in timing was found to be statistically significant using the Wilcoxon Signed Rank Test (W=17.5/ 10, p= 0.47/ 0.07 (1-tailed)). In word initial position the approach phase for /s/ was found to have increased following therapy. In word final position /s/ was found to have a reduced approach phase in the post-treatment condition which was not statistically significant (W=4, p= 0.09 (1-tailed)).

### 3.3.2. Constriction Phase

Mean average constriction phase times are shown in Appendix G for each phoneme in each position, in both conditions. Figure 3.9 illustrates the mean length of the constriction phases for each phoneme, in each position, both before and after treatment.

**Figure 3.9.** Mean constriction phase durations pre and post-treatment.

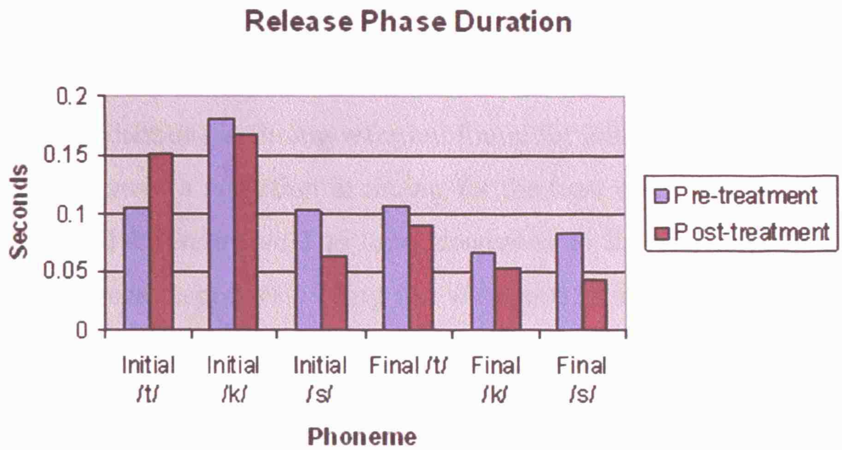



The mean average constriction phases were found to have reduced for all phonemes in both word positions following treatment, with the exception of word initial /s/ which increased in duration in the post-treatment condition. The reduction in timing observed post-treatment for initial /t/ was found not to be significant according to the Wilcoxon Signed Rank Test ($W=15.5$, $p= 0.11$ (1-tailed)). The reduction in the constriction phase found for word final /t/ was found to be statistically significant at the 0.05 probability level ($W=5$, $p=0.02$ (1-tailed)). The constriction phase timing reductions observed in the post-treatment condition for word initial and final /k/ were found not to be statistically significant (W= 11/ 18, p= 0.09/ 0.5 (1-tailed)). The reduction found in constriction phase time after treatment for word final /s/ was also found not to be significant ($W=4$, $p= 0.08$ (1-tailed)).

### 3.3.3. Release Phase

Mean average release phase times are shown in Appendix G for each phoneme in each position, in both pre- and post- treatment conditions. Figure 3.10 illustrates the length of the release phases for each phoneme, in each position, both before and after treatment.

**Figure 3.10.** Mean release phase durations pre and post-treatment.




A reduction in the timing of the release phase was found for all sounds in both positions following treatment with the exception of word initial /t/. None of the reductions in release phase time was found to be statistically significant using the Wilcoxon Signed Rank Test. Word final /t/: W=13, p=.13 (1-tailed), word initial /k/: W=12, p=2 (1-tailed), word final /k/: W=17, p=.044 (1-tailed), word initial /s/: W=14.5, p= 0.09 (1-tailed), word final /s/: W=1, p= .38 (1-tailed).

### 3.3.4. Total phoneme duration

Mean average total duration times for each phoneme in each position, both before and after treatment is shown in Appendix G. Figure 3.11 illustrates the length of the total duration of each phoneme, in each position, both before and after treatment.

**Figure 3.11.** Mean total phoneme durations pre and post-treatment.

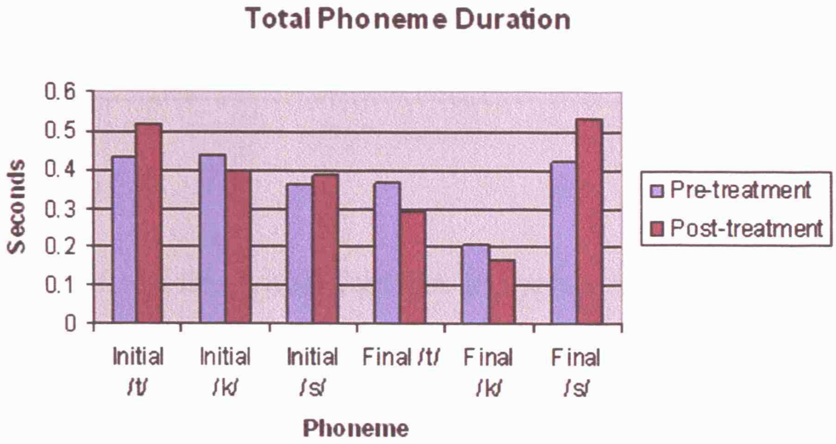



Figure 3.11 illustrates the reduction found in overall timing for initial /k/, final /t/ and final /k/. Reductions in timing were not found for initial /t/, initial /s/ or final /s/. Of those which showed a reduction in timing for the total duration of the productions initial /k/ and final /t/ were found to have decreased to the 0.05 and 0.01 levels of statistical significance respectively using the Wilcoxon Signed Rank Test (W= 6.5/ 0, p= 0.29/ 0.002 (1-tailed)). The reduction found for final /k/ was not found to be statistically significant (W=13, p=0.24 (1-tailed)).

Inter-rater reliability of a sample of the data (five repetitions each of five stimuli) was found to be 100% reliable for both the approach and constriction phase times to one decimal place. Reliability was 40% for both the release phases and the total average scores for each sound in each position.

# 4.0 DISCUSSION

The use of real-time visual feedback in speech and language therapy is a relatively new approach to the treatment of articulation disorders. While there have been a limited number of case studies evaluating the use of EPG for children with neurologically based impairments such as Cerebral Palsy (Gibbon and Wood, 2002) Worster-Drought Syndrome (Morgan-Barry, 1995) and cerebellar dysarthria (Leitch et al., 1998), the current study was the first to our knowledge to trial the use of EPG in the treatment of dysarthria associated with a diffuse TBI acquired in childhood. The findings should therefore be interpreted as preliminary when discussing the value of EPG in the treatment of this client group. The study set out to systematically evaluate speech parameters before and after therapy using EPG in order to meet the following three aims:

## 4.1 AIMS

### 4.1.1 Perceptual

To determine whether there were perceptual improvements made in speech following the treatment. It was hypothesised that a change in perceptually rated articulatory parameters would be observed.

### 4.1.2. Spatial

To determine whether there were post-treatment changes in spatial tongue to palate placement for three sounds: /t/, /k/, and /s/. It was hypothesised that the subject would achieve more accurate tongue to palate placement following treatment.

### 4.1.3. Timing

To determine whether there was a reduction in timing following therapy for each of the three sounds treated. It was hypothesised that a reduction in timing would be observed post-treatment through speech practice effects.

## 4.2 FINDINGS

### 4.2.1. Perceptual

Throughout the therapy process AB progressed rapidly through the stages of the treatment, and was only able to move to the next treatment goal when he had achieved 10 correct productions consecutively at each stage. Despite this progress observed in clinic, the perceptual dysarthria rating assessment (Duffy, 2005) administered pre- and post- treatment showed little change in the articulatory parameters of speech targeted by the therapy technique (Table 3.1). This was with the exception of phoneme duration which was found to have reliably reduced in severity following treatment (Table 3.1). The imprecise consonants characterising AB's speech were found to have reduced in severity following treatment in the intra-rater reliability scoring (Table 3.1). The VMPAC found that changes made post-treatment were in the areas of global and focal motor control. These findings represent an improvement in the global motor control of tone, respiration, phonation, reflexes, and vegetative functions of chewing and swallowing; and the focal volitional oro-motor movements of the mandible, lips and face, and tongue both in isolation and in combination. However despite gains in the integrity of the underlying motor systems indicated through the VMPAC, no improvement was found specifically in AB's articulatory speech characteristics, suggesting that the improvements observed in isolated oro-motor movement tasks were not generalised to connected speech.

Overall the changes in articulatory patterns observed in clinic, and the improvements noted in isolated oro-motor control tasks, were not found to have impacted significantly on the perceptual ratings of AB's speech characteristics. This finding could potentially be explained by a number of factors.

Firstly, whilst the study incorporated the use of functional phrases toward the end of the treatment, no generalisation work in the home environment was included. Other studies which have found EPG to be effective incorporated regular use of a portable EPG unit at home in order to achieve generalisation of clinic work into spontaneous speech and this may have increased the functional outcome (Gibbon & Wood, 2002). However the frequency, duration and method of practice carried out at home can be difficult to control and therefore the conclusions in the present study are based on having controlled the frequency of practice and the method adopted, albeit in a clinical setting.

The generalisation of gains made with EPG into everyday speech was achieved in an adult case study which trialled the use of EPG with a client following TBI (Hartelius et al. 2005). Spontaneous speech and text reading exercises were used in order to achieve the generalisation, and the results of the study noted an increase of 10% in functional intelligibility. The methods of rating and feedback during this phase of treatment were not detailed, stating that feedback was kinaesthetic and auditory, pertaining to a traditional type of approach to generalisation. Traditional articulation approaches have been advocated in another study for generalising the contact patterns achieved by EPG into connected speech (Gibbon & Wood, 2002)

As in the present study Dagenais et al. (1994) reported a case in which a paediatric subject with a developmental phonological impairment showed improvement in articulatory precision with EPG in the clinic, but a further block of therapy was necessary in order to achieve generalisation to functional settings.

These findings are compatible with theories of motor learning such that *segmentation* of a task, i.e. practising the production of a sound outside of its functional environment (Wightman & Lintern, 1985), is an effective method of learning so long as it is reintroduced into the whole, highly organised behaviour (Naylor & Briggs, 1963); in this case conversational speech. Therefore while EPG has been found to be effective in the learning of new motor patterns through segmentation of the task, these patterns require use in natural speech practice in order to achieve generalisation. In the present study this may account for the improvements noted in the VMPAC parameters of global and focal oro-motor control as these require isolated oral movements; and the lack of change in speech characteristics which constitute more complex speech specific tasks. This theory is supported by other clinical findings such that approaches which focus on the integrity of oro-motor skills underpinning speech have been found to be ineffective in promoting change in functional speech production (Guisti Braislin & Cascella, 2005).

Secondly, the limited changes seen in the post-treatment perceptual assessment may be related to the severity of AB's dysarthria before treatment. In the pre-treatment condition AB's articulation was characterised by a mild dysarthria, with mildly prolonged and imprecise phonemes. AB's speech was 96% intelligible at the single word level prior to treatment, and those words which were unintelligible were due to speech characteristics other than labial-palatal contact such as resonance and phonation. These residual speech characteristics not targeted by EPG might therefore have prevented an increase in intelligibility on such an assessment given that the treatment focussed on the articulatory parameter of AB's dysarthria. Hypernasality has previously been found to prevent functional sound contrasts being established in a study using EPG (Morgan-Barry, 1995). This was said to have led to minimal functional improvement despite spatial changes noted in the post-treatment assessments.

In studies that have found EPG to be effective functionally, the technique has been of maximum benefit in helping to create motor patterns for phonemes not currently in a child's inventory (Gibbon & Wood, 2002). A more related study of an adult subject with dysarthria following TBI also found EPG to be effective in this way (Hartelius et al. 2005). The subject was found to be 66% intelligible in the pre-treatment assessment, with his productions of /s/ and /ʃ/ perceived by raters as /t/ providing the focus for treatment. Therefore the increase noted in functional intelligibility was due to the emergence of this contrast. Prior to treatment AB was able to produce a full adult phonetic inventory (GFTA-2) and therefore producing sounds in contrast was not the aim of treatment. This may account for the lack of increase noted in AB's intelligibility in the present study.

### 4.2.2 Spatial

Quantitative spatial changes were observed in the post-treatment condition in the COG and variability data. Both phonemes /t/ and /k/ showed more anterior and posterior placement respectively, in both word initial and word final positions. These findings were confirmed by the qualitative analysis where consistent changes in the patterns of contacted electrodes for each of the sounds were observed. A consistent pattern of more adequate tongue grooving was observed in the qualitative analysis of /s/. Although these quantitative results indicated spatial changes in AB's articulation, these changes were not sufficient to impact on the perceptual ratings of his speech. These findings are similar to those in a case study of an eight-year-old child with a developmental speech disorder by Friel (1998) such that the EPG therapy was found to be successful in achieving spatial changes in the patterns of lingual-palatal contact rather than changes on functional assessments. As in the present study, the subject was able to use both phonemes to be treated contrastively and intelligibly before therapy (/t/ and /k/). However the findings in the present study are not compatible with an adult case study which noted an overall increase in variability for all sounds treated following EPG treatment, despite a perceptual increase in intelligibility in connected speech (Hartelius et al. 2005). As discussed in section 4.2.1., this increase in intelligibility was due to the emergence of a new phonological contrast between /s/ and /t/ as a result of postural changes, and in spite of more variable productions of each phoneme following treatment.

### 4.2.3. Timing

Overall the quantitative timing data showed no consistent, significant reduction in the overall durations of any of the phonemes in the post-treatment condition. The timing analysis of some phonemes found significant reductions in duration for individual phases of the phoneme; however no consistent findings were noted across the sounds treated. For example /s/ in a word initial position was found to have a shorter release phase following treatment, however the overall duration of word initial /s/ as a whole phoneme increased following treatment. Similar findings were documented in an EPG treatment study of an eight-year-old boy with cerebral palsy in which little quantitative difference in timing following treatment was observed, despite the hypothesis of finding a decrease in phoneme duration as a result of the practice effect (Gibbon & Wood, 2002). Similarly in a multiple baseline study of a man with acquired dysarthria, Hartelius et al. (2005) noted an increase in phoneme duration over a period of three to four weeks. It was concluded that this increase in overall timing was observed as a result of a focus on spatial changes during treatment.

As with previous studies evaluating the use of EPG, the present study found the technique to be a useful diagnostic tool in measuring phoneme duration as well as spatial aspects of articulation (Gibbon & Wood, 2002).

## 4.3 LIMITATIONS OF THE STUDY AND FUTURE DIRECTIONS

### 4.3.1. Methodological limitations

Some methodological limitations of the present study were identified which, may lead to more significant findings if controlled in future research in this area.

As this was a preliminary study, treatment was only provided for one subject. Case studies are useful in detailing and discussing which therapies work for which individuals, however the target client group is a heterogeneous one and inferences cannot be drawn from the results of the present study when providing treatment for, or carrying out investigations with, other children with dysarthria following TBI. In addition TBI often results in diffuse damage leading to vastly different presentations in subjects making it difficult to group subjects together in order to conduct group studies. Group statistics are then often difficult to interpret based on these differences in presentation and subsequent response to treatment. In order to reach more conclusive findings, a larger number of subjects are required, and a series of case studies might be a more appropriate, realistic, and informative approach to further treatment studies focussing on this client group.

The current study did not experimentally include control subjects or compare EPG with a more conventional approach to articulation therapy. This would have provided an opportunity to assess whether the spatial changes observed were significant compared with results of a traditional approach, or compared with an alternative group of control subjects with a different type of acquired dysarthria, for example children with dysarthria following surgical treatment for posterior fossa tumour.

A maintenance assessment or multiple baseline design would have provided valuable information as to the progress and long term effects of the EPG technique. Such a methodological approach has been used in an adult case study where an EPG assessment was conducted at the beginning, middle and end of treatment (Hartelius et al. 2005). The method of maintenance testing following therapy has also been attempted with the paediatric population with developmental speech disorder (Friel, 1998). However it was found that at the time of the second assessment the subject had outgrown the palate and found it uncomfortable to wear, and therefore the maintenance assessment could not be conducted.

In the developmental EPG treatment case study by Gibbon et al. (1993) a functional assessment was used which focussed on the auditory acceptability of the phonemes treated. For example listeners were asked to judge on a scale of 1-5 how well a production of /t/ or /k/ pertained to the target. This was in contrast to the intelligibility assessment used in the present study whereby success was reliant on sound contrasts e.g. 'tar' and 'car' rather than on the auditory acceptability and articulatory precision of the production. Such an assessment in the present study may have been more sensitive functionally to the subtle spatial changes observed in the EPG assessments. In addition a parent and child checklist may have provided valuable information as to the functional changes occurring in home and educational environments.

### 4.3.2. Electropalatography

In addition to the methodological limitations of the present study, there are further treatment considerations specific to the EPG technique requiring discussion.

One limitation of using EPG with a paediatric client group is the growth and development of a client's oral structures. This causes the palate to become unusable after a period of time and may prevent further blocks of therapy commencing at a later date. The significance of this limitation for the present study was discussed in section 4.3.1., however it is also a consideration for further research in this area, and in the use of EPG in a paediatric clinical setting. EPG palates are an expensive piece of equipment, particularly when they may only be of use for a relatively short period of time with children. An intended solution is the creation of EPG palates that are made from more flexible, easily moulded and adapted materials however these are still in development, (Personal communication with Professor Bruce Murdoch, University of Queensland, August 2006).

EPG aims to remediate lingual-palatal sounds only and is therefore unsuitable for phonemes produced by other articulators such as the lips and teeth. In addition other factors contributing to intelligibility such as resonance and phonation cannot be treated using EPG and such symptoms are likely to remain following treatment (Hartelius et al. 2005). These features may lessen functional improvement if they prevent sound contrasts being established, for example hypernasality (Morgan-Barry, 1995).

The success of EPG treatment requires a certain level and profile of cognitive ability due to the abstract nature of the visual feedback. This is particularly relevant for the client group in the current study as cognitive deficits are a common consequence of TBI (Hanten et al. 2004, Yeates et al. 2005, Levin & Hanten, 2005). However for children who do not respond to traditional approaches EPG may provide a visual representation that is easier to imitate than traditional verbal descriptions, physical prompting and visual demonstrations used to teach sound placements, particularly for those children with accompanying language disorders or a relative visual spatial cognitive strength.

## 4.4 SUMMARY AND CONCLUSIONS

Qualitative assessment of AB's consonant production before and after treatment demonstrated some spatial changes in lingual-palatal contact patterns. The spatial changes observed qualitatively were confirmed by objective EPG assessment which found some changes in COG scores and in the variability of productions. However these were variable and these changes were not consistently noted across all phonemes treated. Despite these changes the perceptual post-treatment assessment found little functional change in the articulatory parameter of AB's speech.

AB's prior access to a full phonological inventory, the mild presentation of his speech disorder at the outset, and his residual dysarthric features may have caused the relatively subtle spatial changes observed to be perceptually insignificant based on the functional assessments used. In addition theories of motor learning and findings from previous studies using EPG suggest that a phase of traditional therapy following the treatment may lead to a better functional outcome through facilitating the generalisation of patterns learned into spontaneous connected speech.

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# Appendix A
## Word list used in instrumental EPG assessment

**Word initial /t/:**

- a tart
- a tick

**Word initial /k/:**

- a cot
- a car

**Word initial /s/:**

- a seat
- a side

**Word final /t/:**

- a tart
- a seat

**Word final /k/:**

- a tick
- a neck

**Word final /s/:**

- a mouse
- a base

## Appendix B
Frames of maximum contact pre- and post-treatment

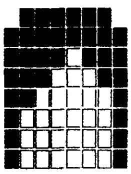
RAW MEAN NUMBER OF ELECTRODES CONTACTED

| Phoneme | Pre-Treatment | Post-Treatment |
|---|---|---|
| Initial /t/ | 49.6 | 46.6 |
| Initial /k/ | 16.35 | 13.8 |
| Initial /s/ | 35.4 | 37.4 |
| Final /t/ | 43.4 | 39.4 |
| Final /k/ | 10.6 | 9.7 |
| Final /s/ | 29.4 | 27.9 |

### *Pre-treatment frames of maximum contact*

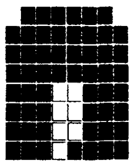
### Word initial /t/ 'a tart'

162



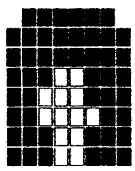
**Production 1**

114



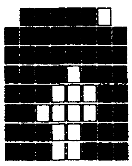
**Production 2**

116



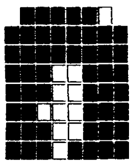
**Production 3**

196



**Production 4**

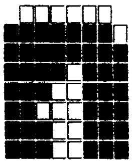
100



**Production 5**

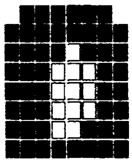
## Word initial /t/ ‘a tick’

107



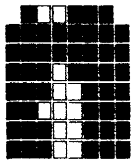
**Production 1**

97



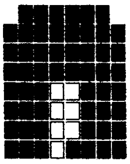
**Production 2**

99



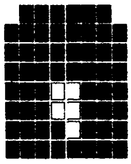
**Production 3**

114



**Production 4**

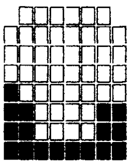
54



**Production 5**

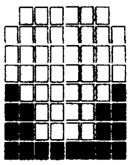
## Word initial /k/ ‘a cot’

93



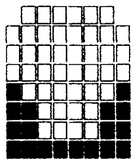
**Production 1**

79



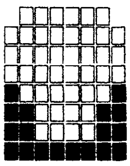
**Production 2**

92



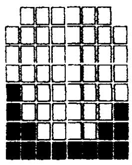
**Production 3**

84



**Production 4**

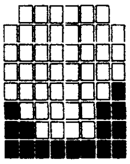
61



**Production 5**

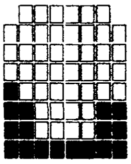
## Word initial /k/ ‘a car’

140



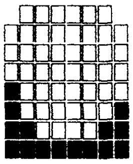
**Production 1**

195



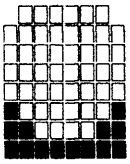
**Production 2**

126



**Production 3**

108

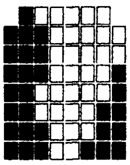


**Production 4**

(Production 2 not recorded)

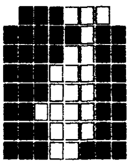
## Word initial /s/ ‘a seat’

175



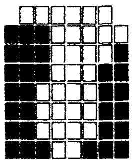
**Production 1**

73



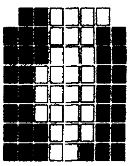
**Production 2**

69



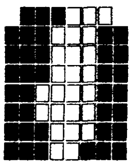
**Production 3**

103



**Production 4**

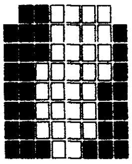
91



**Production 5**

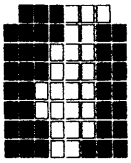
## Word initial /s/ ‘a side’

153



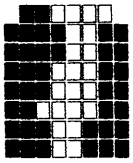
**Production 1**

73



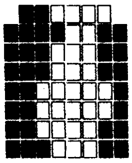
**Production 2**

90



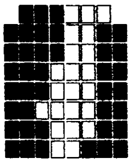
**Production 3**

72



**Production 4**

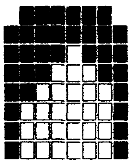
99



**Production 5**

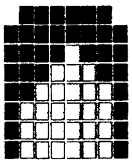
## Word final /t/ ‘a tart’

162



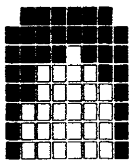
**Production 1**

181



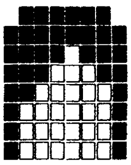
**Production 2**

180



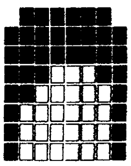
**Production 3**

263



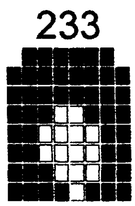
**Production 4**

161

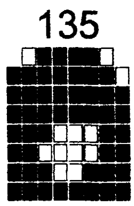


**Production 5**

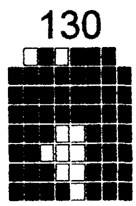
## Word final /t/ ‘a seat’



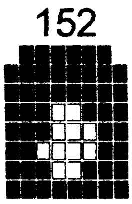

**Production 1**



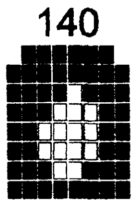

**Production 2**




**Production 3**

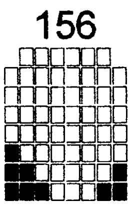



**Production 4**

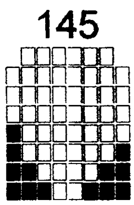



**Production 5**

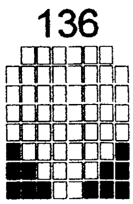
## Word final /k/ ‘a tick’



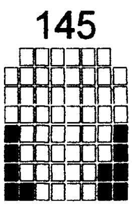

**Production 1**




**Production 2**




**Production 3**

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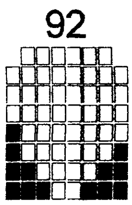
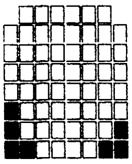



**Production 5**

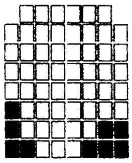
## Word final /k/ 'a neck'

159



**Production 1**

102



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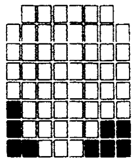
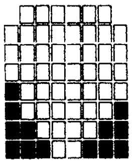
119



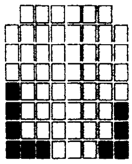
**Production 3**

188



**Production 4**

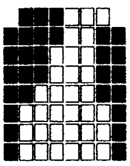
122



**Production 5**

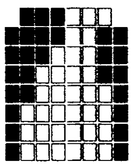
## Word final /s/ 'a mouse'

142



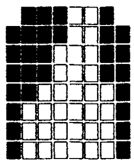
**Production 1**

226



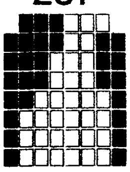
**Production 2**

257



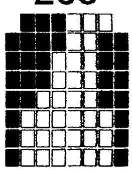
**Production 3**

267



**Production 4**

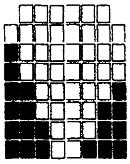
205



**Production 5**

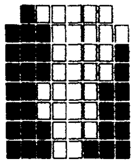
## Word final /s/ ‘a base’

209



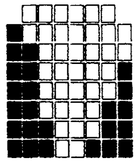
**Production 1**

224



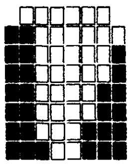
**Production 2**

164



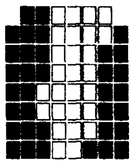
**Production 3**

140



**Production 4**

188

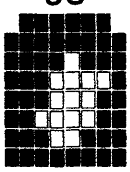


**Production 5**

***Post-treatment frames of maximum contact***

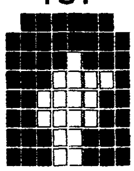
## Word initial /t/: a tart

96



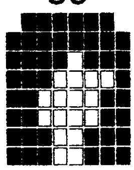
**Production 1**

157



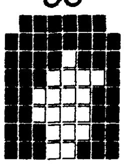
**Production 2**

89

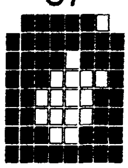


**Production 3**

58

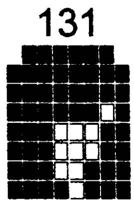


67

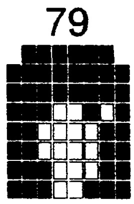


Production 4 Production 5

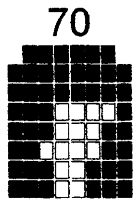
## Word initial /t/: a tick



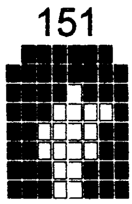

Production 1



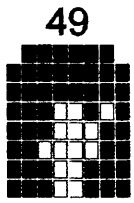

Production 2




Production 3

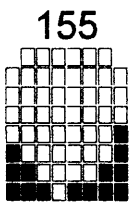



Production 4

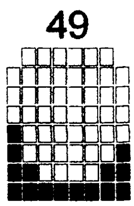



Production 5

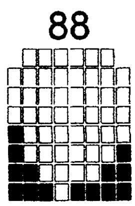
## Word initial /k/: a cot



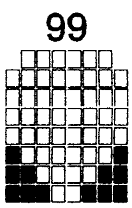

Production 1



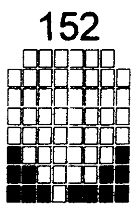

Production 2




Production 3

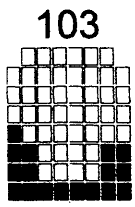



Production 4

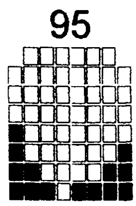



Production 5

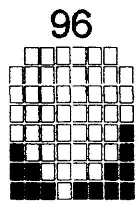
## Word initial /k/: a car



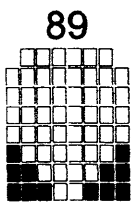

**Production 1**



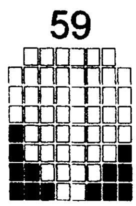

**Production 2**




**Production 3**

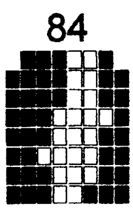



**Production 4**

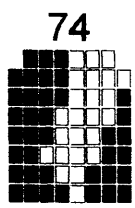



**Production 5**

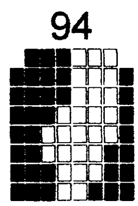
## Word initial /s/: a seat



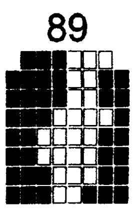

**Production 1**



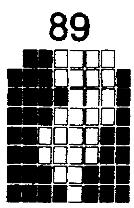

**Production 2**




**Production 3**



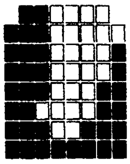

**Production 4**




**Production 5**

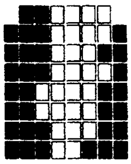
## Word initial /s/: a side

142



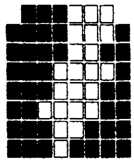
**Production 1**

132



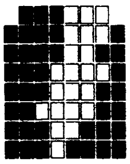
**Production 2**

68



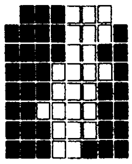
**Production 3**

68



**Production 4**

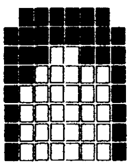
295



**Production 5**

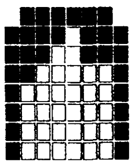
## Word final /t/: a tart

153



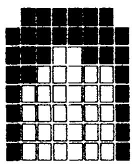
**Production 1**

216



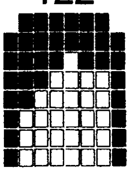
**Production 2**

145



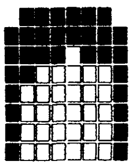
**Production 3**

122



**Production 4**

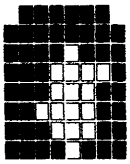
130



**Production 5**

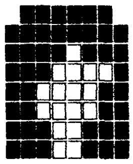
## Word final /t/: a seat

132



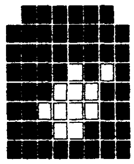
**Production 1**

124



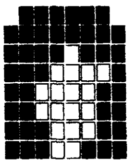
**Production 2**

146



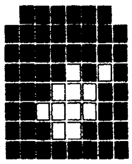
**Production 3**

138



**Production 4**

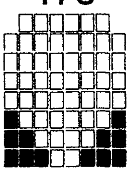
144



**Production 5**

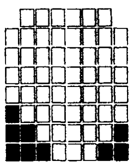
## Word final /k/: a tick

176



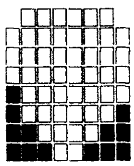
**Production 1**

124



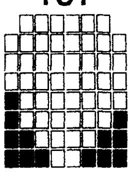
**Production 2**

109



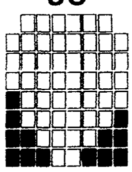
**Production 3**

197



**Production 4**

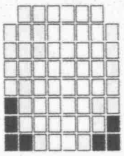
93



**Production 5**

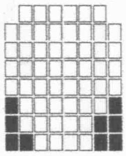
## Word final /k/: a neck

141



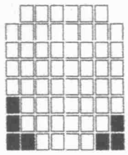
**Production 1**

150



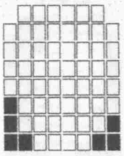
**Production 2**

171



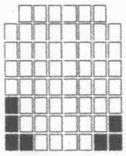
**Production 3**

142



**Production 4**

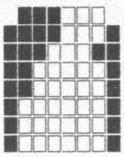
126



**Production 5**

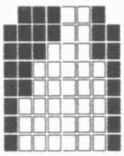
## Word final /s/: a mouse

157



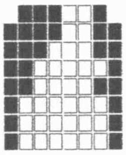
**Production 1**

160



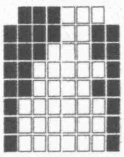
**Production 2**

156



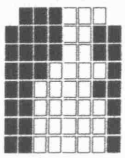
**Production 3**

156



**Production 4**

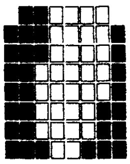
113



**Production 5**

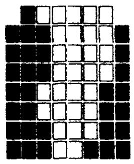
## Word final /s/: a base

170



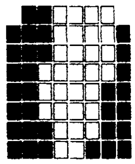
**Production 1**

130



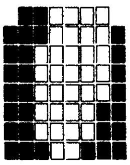
**Production 2**

135



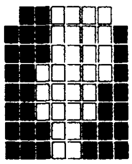
**Production 3**

145



**Production 4**

195



**Production 5**

# Appendix C
## Raw variability scores pre- and post- treatment

| Phoneme | Pre-Treatment variability | Post-Treatment variability |
|---|---|---|
| Initial /t/ | 9.46 | 3.385 |
| Initial /k/ | 6.665 | 7.57 |
| Initial /s/ | 9.025 | 6.255 |
| Final /t/ | 3.645 | 4.215 |
| Final /k/ | 14.89 | 6.065 |
| Final /s/ | 7.33 | 5.385 |

## Appendix D
Example of variability index calculation

The grid below contains 62 filled cells, with each cell representing one electrode of the artificial EPG palate. Each cell contains a number representing the percentage of times the corresponding electrode was contacted over five productions, with 100 being all of the time, and 0 being none of the time. Those electrodes contacted less consistently than 0% or 100% were counted and grouped into being either 20% (values of 20 or 80) or 40% (values of 40 or 60) away from a consistent value (0% or 100)%. These totals were multiplied respectively by their frequency e.g. there were 16 cells below with values of either 20 or 80; and five cells with values of 40 or 60. These two values were then added together, and divided by the number of electrodes contacted in total (including those contacted 100% of the time) in order to give a variability value.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 100 | 100 | 100 | 100 | 100 | 60 | |
| 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 100 | 100 | 100 | 100 | 80 | 100 | 100 | 100 |
| 100 | 100 | 100 | 40 | 20 | 20 | 100 | 100 |
| 100 | 100 | 60 | 0 | 0 | 60 | 80 | 100 |
| 100 | 80 | 20 | 0 | 0 | 20 | 80 | 100 |
| 100 | 80 | 80 | 0 | 0 | 80 | 80 | 100 |
| 100 | 80 | 80 | 0 | 40 | 80 | 80 | 100 |

**Word initial /t/: a tart** (% contacted)

(16x20) + (5x40) / 55 = **9.45**

# Appendix E
## Raw COG scores pre- and post- treatment

| Phoneme | Pre-Treatment COG | Post-Treatment COG |
|---|---|---|
| Initial /t/ | 4.145 | 4.185 |
| Initial /k/ | 1.335 | 1.29 |
| Initial /s/ | 3.67 | 3.61 |
| Final /t/ | 4.495 | 4.6 |
| Final /k/ | 1.255 | 1.185 |
| Final /s/ | 3.78 | 3.9 |

## Appendix F

Formula used to calculate COG (From Gibbon et al., 2003)

$$\frac{(0.5 \times R8) + (1.5 \times R7) + (2.5 \times R6) + (3.5 \times R5) + (4.5 \times R4) + (5.5 \times R3) + (6.5 \times R2) + (7.5 \times R1)}{(R8 + R7 + R6 + R5 + R4 + R3 + R2 + R1)}$$

**R**= Row of electrodes with R1 being the most anterior row of the EPG palate.

# Appendix G
Raw phoneme times pre- and post- treatment

**APPROACH PHASE**

| Phoneme | Pre-Treatment (secs) | Post-Treatment (secs) |
|---|---|---|
| Initial /t/ | 0.2044 | 0.2536 |
| Initial /k/ | 0.18035 | 0.179 |
| Initial /s/ | 0.2016 | 0.2344 |
| Final /t/ | 0.1156 | 0.076 |
| Final /k/ | 0.0604 | 0.03455 |
| Final /s/ | 0.1747 | 0.163875 |

**CONSTRICTION PHASE**

| Phoneme | Pre-Treatment (secs) | Post-Treatment (secs) |
|---|---|---|
| Initial /t/ | 0.1199 | 0.1127 |
| Initial /k/ | 0.07525 | 0.0553 |
| Initial /s/ | 0.0589 | 0.0886 |
| Final /t/ | 0.1424 | 0.1266 |
| Final /k/ | 0.07965 | 0.07725 |
| Final /s/ | 0.32925 | 0.32065 |

**RELEASE PHASE**

| Phoneme | Pre-Treatment (secs) | Post-Treatment (secs) |
|---|---|---|
| Initial /t/ | 0.1049 | 0.1514 |
| Initial /k/ | 0.1804 | 0.1657 |
| Initial /s/ | 0.1018 | 0.064 |
| Final /t/ | 0.1068 | 0.0907 |
| Final /k/ | 0.067525 | 0.05325 |
| Final /s/ | 0.08225 | 0.0431 |

**TOTAL DURATION**

| Phoneme | Pre-Treatment (secs) | Post-Treatment (secs) |
|---|---|---|
| Initial /t/ | 0.4292 | 0.5177 |
| Initial /k/ | 0.436 | 0.4 |
| Initial /s/ | 0.3623 | 0.387 |
| Final /t/ | 0.3648 | 0.2933 |
| Final /k/ | 0.207575 | 0.1655 |
| Final /s/ | 0.4233 | 0.53 |

## Appendix H
EPG treatment plan

Aim 1: Relating terminology to lingual-palatal positioning. For AB to learn the terminology that will be used consistently during therapy for guiding tongue placement during auditory and visual feedback.

**Activity**: AB will be required to use the terms 'front' for alveolar contact; 'back' for velar contact; 'middle' for palatal contact; 'the sides' (with gap in centre) for fricatives.

**Rating**: The therapist will be wearing her pseudopalate and will make various lingual-palatal contact patterns. AB will be required to consistently provide the correct terminology for the contact patterns when prompted. He will be required to provide the correct terminology to a percentage correct of 100% (5/5 trials for each position).

Aim 2: Kinaesthetic awareness of lingual-palatal positioning. For AB to gain awareness of the articulators and their position to each other, including gaining kinaesthetic awareness of lingual-palatal contact.

**Activity**:
AB will be required to place his tongue on the palate to cover the entire palate, then to consistently isolate tongue movement to either the anterior, middle, posterior or lateral parts of the palate using visual feedback. He will also be required to practice creating a gap in the mid-saggital plane of the palate by placing his tongue laterally on both sides.

**Rating**: AB will be required to perform each of these movements to command to a percentage correct of 100% (5/5 trials).

Aim 3: Self-identification of error patterns. For AB to be aware of his error patterns for the sounds and to understand what will be targeted in therapy and why.

**Activity**:
Using the EPG feedback page, the therapist will open files for various lingual-palatal contact patterns for sounds AB (seen on the left hand side of the screen) and contrast these with the acceptable pattern (seen on the right hand side of the screen). At this stage the therapist will simply be talking to AB about the error patterns and explaining why it is important to have the correct placement (i.e. if you have 'a gap' for a 'stopping' sound then you make a 'hissing' sound instead, etc). AB will be able to try and produce the different sounds without visual feedback as part of kinaesthetic/oral awareness.

**Rating**: For AB to identify whether a range of his contact patterns (selected by the therapist and displayed on the left hand side of the screen) are acceptable or unacceptable productions of the sounds that appear on the right hand side of the screen.

Aim 4: Production of isolated lingual-palatal articulatory postures with visual feedback. For AB to be able to produce isolated articulatory lingual-palatal contact patterns (no voicing or aistream, just lingual-palatal posturing) for the sounds he has in error *using visual feedback.*

**Activity**: AB will be required to copy the template on the right hand side of the screen that shows an acceptable lingual-palatal contact pattern for the sound/s he has in error (i.e., alveolar stop; alveolar fricative; velar stop).

**Rating**: AB will be required to achieve each of these lingual-palatal contact patterns and hold them for 3 seconds to command to a percentage correct of 100% (10/10 trials per sound).

Aim 5: Production of isolated lingual-palatal articulatory postures without visual feedback. For AB to be able to produce isolated articulatory lingual-palatal contact patterns (no voicing or aistream, just lingual-palatal posturing) for the sounds he has in error *without visual feedback.*

**Activity**: AB will be required to perform an acceptable lingual-palatal contact pattern for the sound/s he has in error without looking at the screen, but focusing on the memory of kinaesthetic information of how the sound felt (and perhaps visual imagery?) to recreate the sound (i.e., alveolar stop; alveolar fricative; velar stop). The therapist is still required to look at the screen in order to assess AB's production of the postures.

**Rating**: AB will be required to achieve each of these lingual-palatal contact patterns without visual feedback, and to hold them for 3 seconds to command to a percentage correct of 100% (5/5 trials per sound).

Aim 6: Production of isolated lingual-palatal articulatory postures without palate. For AB to be able to produce isolated articulatory lingual-palatal contact patterns (no voicing or aistream, just lingual-palatal posturing) for the sounds he has in error *without wearing the EPG palate.*

**Activity**: AB will be required to perform an acceptable lingual-palatal contact pattern for the sound/s he has in error without looking at the screen, and without wearing the palate – and using the memory of kinaesthetic information of how the sound felt (and perhaps visual imagery?) to recreate the sound (i.e., alveolar stop; alveolar fricative; velar stop). The therapist will be required to (visual) perceptually try to rate whether AB is producing the correct postures.

**Rating**: AB will be required to achieve each of these lingual-palatal contact patterns without wearing the palate, and to hold them for 3 seconds to command to a percentage correct of 100% (5/5 trials per sound).

Aim 7: Production of alternating lingual-palatal articulatory postures with visual feedback. For AB to be able to perform alternating lingual-palatal contact patterns (no voicing or airstream, just lingual-palatal posturing) for the sounds he has in error and already in his repertoire *using visual feedback.*

**Activity**: AB will be required to perform acceptable alternating lingual-palatal contact patterns for the sound/s he has in error using the screen for visual feedback.
i). alveolar stop posture followed by velar stop posture and vice-versa: t k; k t
ii). alveolar fricative followed by velar stop and vice-versa: s k; k s
iii). alveolar stop followed by alveolar fricative and vice-versa: t s; s t

**Rating**: AB will be required to achieve each of these alternating contact patterns with visual feedback (holding each for 2 seconds) to command to a percentage correct of 100% (5/5 trials per alternating sequence).

**Aim 8**: Production of alternating lingual-palatal articulatory postures without visual feedback. For AB to be able to perform alternating lingual-palatal contact patterns (no voicing or airstream, just lingual-palatal posturing) for the sounds he has in error and already in his repertoire without *visual feedback.*

**Activity**: AB will be required to perform acceptable alternating lingual-palatal contact patterns for the sound/s he has in error *without visual feedback.*
i). alveolar stop posture followed by velar stop posture and vice-versa: t k; k t
ii). alveolar fricative followed by velar stop and vice-versa: s k; k s
iii). alveolar stop followed by alveolar fricative and vice-versa: t s; s t

**Rating**: AB will be required to achieve each of these alternating contact patterns *without visual feedback* (holding each for 2 seconds) to command to a percentage correct of 100% (5/5 trials per alternating sequence).

**Aim 9**: Production of alternating lingual-palatal articulatory postures without wearing the EPG palate. For AB to be able to perform alternating lingual-palatal contact patterns (no voicing or airstream, just lingual-palatal posturing) for the sounds he has in error and already in his repertoire without *visual feedback.*

**Activity**: AB will be required to perform acceptable alternating lingual-palatal contact patterns for the sound/s he has in error *without wearing the EPG palate.*
i). alveolar stop posture followed by velar stop posture and vice-versa: t k; k t
ii). alveolar fricative followed by velar stop and vice-versa: s k; k s
iii). alveolar stop followed by alveolar fricative and vice-versa: t s; s t

**Rating**: AB will be required to achieve each of these alternating contact patterns *without visual feedback* (holding each for 2 seconds) to command to a percentage correct of 100% (5/5 trials per alternating sequence).

**Aim 10**: Identifying sound types based on airstream and lingual-palatal contact. For AB to learn the terminology that will be used consistently during therapy in relation to categories of sounds to help describe the relationship between aistream and lingual-palatal position. This skill is required for guiding correct placement and production during auditory and visual feedback.

**Activity**: The therapist will be wearing her pseudopalate and will make various lingual-palatal contact patterns. AB will be required to identify the type of sounds, i.e.: 'stopping' sounds (stops) and 'blowing' sounds (fricatives).

**Rating**: AB will be required to consistently provide the correct terminology for the contact patterns when prompted. He will be required to provide the correct terminology to a percentage correct of 100% (5/5 trials for each position).

**Aim 11**:
a) Alternating articulatory movements between alveolar oral stop consonant /t/ and vowels in CV structures with visual feedback. For AB to learn to produce the correct lingual-palatal consonant posture in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonant is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of CV structures for the alveolar stop consonant /t/.

**Rating**: AB will be required to correctly produce the CV structures when prompted with visual feedback. He will be required to provide the correct production to a percentage correct of 100% (5/5 trials for each CV structure).

**Aim 11**:
b) Alternating articulatory movements between alveolar oral stop consonant /t/ and vowels in CV structures without visual feedback. For AB to learn to produce the correct lingual-palatal consonant posture in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonant is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of CV structures for the alveolar stop consonant /t/ without visual feedback (i.e. the therapist will block the screen from AB, but will be able to see the screen herself to rate the productions).

**Rating**: AB will be required to correctly produce the CV structures when prompted without visual feedback. He will be required to provide the correct production to a percentage correct of 100% (5/5 trials for each CV structure).

**Aim 11**:
c) Alternating articulatory movements between alveolar oral stop consonant /t/ and vowels in CV structures without the palate insitu. For AB to learn to produce the correct lingual-palatal consonant posture in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonant is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of CV structures for each of the alveolar stop consonants (t, d, n) without the palate insitu.

**Rating**: AB will be required to correctly produce the CV structures when prompted without the palate insitu. He will be required to provide the correct production to a percentage correct of 100% (5/5 trials for each CV structure).

**Aim 12:**
a) Alternating articulatory movements between velar oral stop consonant /k/ and vowels in CV structures with visual feedback. For AB to learn to produce the correct lingual-palatal consonant posture in combination with vowels. This skill is required to

ensure the motor program for the lingual-palatal consonant is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of CV structures for the velar oral stop consonant /k/.

**Rating**: AB will be required to correctly produce the CV structures when prompted with visual feedback. He will be required to provide the correct production to a percentage correct of 100% (10/10 trials for each CV structure).

<u>**Aim 12**</u>:
b) Alternating articulatory movements between velar oral stop consonant /k/ and vowels in CV structures without visual feedback. For AB to learn to produce the correct lingual-palatal consonant posture in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonant is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of CV structures for the velar oral stop consonant /k/ without visual feedback (i.e. the therapist will block the screen from AB, but will be able to see the screen herself to rate the productions).

**Rating**: AB will be required to correctly produce the CV structures when prompted without visual feedback. He will be required to provide the correct production to a percentage correct of 100% (10/10 trials for each CV structure).

<u>**Aim 12**</u>:
c) Alternating articulatory movements between velar oral stop consonant /k/ and vowels in CV structures without the palate insitu. For AB to learn to produce the correct lingual-palatal consonant posture in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonant is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of CV structures for the velar oral stop consonant /k/ without the palate insitu.

**Rating**: AB will be required to correctly produce the CV structures when prompted without the palate insitu. He will be required to provide the correct production to a percentage correct of 100% (10/10 trials for each CV structure).

<u>**Aim 13:**</u>
a) Alternating articulatory movements between voiceless alveolar fricative consonant /s/ and vowels in CV structures with visual feedback. For AB to learn to produce the correct lingual-palatal consonant posture in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonant is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of CV structures for the voiceless alveolar fricative /s/.

**Rating**: AB will be required to correctly produce the CV structures when prompted with visual feedback. He will be required to provide the correct production to a percentage correct of 100% (10/10 trials for each CV structure).

<u>**Aim 13**</u>:
b) Alternating articulatory movements between voiceless alveolar fricative consonant /s/ and vowels in CV structures without visual feedback. For AB to learn to produce the correct lingual-palatal consonant posture in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonant is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of CV structures for each of the voiceless post/alveolar fricative consonants (s, ʃ) without visual feedback (i.e. the therapist will block the screen from AB, but will be able to see the screen herself to rate the productions).

**Rating**: AB will be required to correctly produce the CV structures when prompted without visual feedback. He will be required to provide the correct production to a percentage correct of 100% (10/10 trials for each CV structure).

<u>**Aim 13**</u>:
c) Alternating articulatory movements between voiceless alveolar fricative consonant /s/ and vowels in CV structures without the palate insitu. For AB to learn to produce the correct lingual-palatal consonant posture in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonant is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of CV structures for the voiceless alveolar fricative consonant /s/ without the palate insitu.

**Rating**: AB will be required to correctly produce the CV structures when prompted without the palate insitu. He will be required to provide the correct production to a percentage correct of 100% (10/10 trials for each CV structure).

<u>**Aim 14**</u>:
a) Alternating articulatory movements between alveolar oral stop consonant /t/ and vowels in VC structures with visual feedback. For AB to learn to produce the correct lingual-palatal consonant posture in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonant is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of VC structures for the alveolar stop consonant /t/.

**Rating**: AB will be required to correctly produce the VC structures when prompted with visual feedback. He will be required to provide the correct production to a percentage correct of 100% (10/10 trials for each VC structure).

Aim 14:
b) Alternating articulatory movements between alveolar oral stop consonant /t/ and vowels in VC structures without visual feedback. For AB to learn to produce the correct lingual-palatal consonant posture in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonant is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of VC structures for the alveolar stop consonant /t/ without visual feedback (i.e. the therapist will block the screen from AB, but will be able to see the screen herself to rate the productions).

**Rating**: AB will be required to correctly produce the VC structures when prompted without visual feedback. He will be required to provide the correct production to a percentage correct of 100% (10/10 trials for each VC structure).

Aim 14:
c) Alternating articulatory movements between alveolar oral stop consonant /t/ and vowels in VC structures without the palate insitu. For AB to learn to produce the correct lingual-palatal consonant posture in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonant is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of VC structures for the alveolar stop consonant /t/ without the palate insitu.

**Rating**: AB will be required to correctly produce the VC structures when prompted without the palate insitu. He will be required to provide the correct production to a percentage correct of 100% (10/10 trials for each VC structure).

Aim 15:
a) Alternating articulatory movements between velar oral stop consonant /k/ and vowels in VC structures with visual feedback. For AB to learn to produce the correct lingual-palatal consonant posture in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonants is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of VC structures for the velar oral stop consonant /k/.

**Rating**: AB will be required to correctly produce the VC structures when prompted with visual feedback. He will be required to provide the correct production to a percentage correct of 100% (10/10 trials for each VC structure).

Aim 15:
b) Alternating articulatory movements between velar oral stop consonant /k/ and vowels in VC structures without visual feedback. For AB to learn to produce the correct lingual-palatal consonant posture in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonant is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of VC structures for the velar oral stop consonant /k/ without visual feedback (i.e. the therapist will block the screen from AB, but will be able to see the screen herself to rate the productions).

**Rating**: AB will be required to correctly produce the VC structures when prompted without visual feedback. He will be required to provide the correct production to a percentage correct of 100% (10/10 trials for each VC structure).

**Aim 15**:
c) Alternating articulatory movements between velar oral stop consonant /k/ and vowels in VC structures without the palate insitu. For AB to learn to produce the correct lingual-palatal consonant posture in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonant is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of VC structures for the velar oral stop consonant /k/without the palate insitu.

**Rating**: AB will be required to correctly produce the VC structures when prompted without the palate insitu. He will be required to provide the correct production to a percentage correct of 100% (10/10 trials for each VC structure).

**Aim 16:**
a) Alternating articulatory movements between voiceless alveolar fricative consonant /s/ and vowels in VC structures with visual feedback. For AB to learn to produce the correct lingual-palatal consonant posture in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonant is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of VC structures for the voiceless post/alveolar fricative /s/.

**Rating**: AB will be required to correctly produce the VC structures when prompted with visual feedback. He will be required to provide the correct production to a percentage correct of 100% (10/10 trials for each VC structure).

**Aim 16**:
b) Alternating articulatory movements between voiceless alveolar fricative consonant /s/ and vowels in VC structures without visual feedback. For AB to learn to produce the correct lingual-palatal consonant posture in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonant is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of VC structures for the voiceless alveolar fricative consonant /s/ without visual feedback (i.e. the therapist will block the screen from AB, but will be able to see the screen herself to rate the productions).

**Rating**: AB will be required to correctly produce the VC structures when prompted without visual feedback. He will be required to provide the correct production to a percentage correct of 100% (10/10 trials for each VC structure).

Aim 16:
c) Alternating articulatory movements between voiceless alveolar fricative consonant /s/ and vowels in VC structures without the palate insitu. For AB to learn to produce the correct lingual-palatal consonant posture in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonant is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of VC structures for the voiceless alveolar fricative consonant /s/ without the palate insitu.

**Rating**: AB will be required to correctly produce the VC structures when prompted without the palate insitu. He will be required to provide the correct production to a percentage correct of 100% (10/10 trials for each VC structure).

Aim 17:
a) For AB to produce single words beginning or ending in either voiceless velar stops or voiceless alveolar stops. This will require alternating articulatory movements from the front to the back of the palate, with varying vowel combinations. For AB to learn to produce the correct lingual-palatal consonant postures in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonants is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of C1VC2 structures where the C1 is either a velar or alveolar stop and C2 is the alternative of C1. AB will have visual feedback and will have the palate insitu.

**Rating**: AB will be required to correctly produce the C1VC2 structures when prompted without the palate insitu. He will be required to provide the correct production to a percentage correct of 100% (10/10 trials for each CVC structure).

Aim 17:
b) For AB to produce single words beginning or ending in either voiceless velar stops or voiceless alveolar stops. This will require alternating articulatory movements from the front to the back of the palate, with varying vowel combinations. For AB to learn to produce the correct lingual-palatal consonant postures in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonants is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of C1VC2 structures where the C1 is either a velar or alveolar stop and C2 is the alternative of C1. AB will not have visual feedback but will have the palate insitu.

**Rating**: AB will be required to correctly produce the C1VC2 structures when prompted with the palate insitu without visual feedback. He will be required to provide the correct production to a percentage correct of 100% (10/10 trials for each CVC structure).

Aim 17:
c) For AB to produce single words beginning or ending in either voiceless velar stops or voiceless alveolar stops. This will require alternating articulatory movements from the front to the back of the palate, with varying vowel combinations. For AB to learn

to produce the correct lingual-palatal consonant postures in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonants is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of C1VC2 structures where the C1 is either a velar or alveolar stop and C2 is the alternative of C1. AB will not have visual feedback but will have the palate insitu.

**Rating**: AB will be required to correctly produce the C1VC2 structures when prompted with the palate insitu without visual feedback. He will be required to provide the correct production to a percentage correct of 100% (10/10 trials for each CVC structure).

**Aim 18**:
a) For AB to produce single words beginning or ending in a voiceless alveolar fricative or voiceless alveolar or velar stops. This will require alternating articulatory movements in regard to placement, and alterations in manner of articulation, in addition to varying vowel combinations. For AB to learn to produce the correct lingual-palatal consonant postures in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonants is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of C1VC2 structures where the C1 is either a voiceless alveolar fricative or voiceless alveolar or velar stop and C2 is the alternative of C1. AB will have visual feedback and will have the palate insitu.

**Rating**: AB will be required to correctly produce the C1VC2 structures when prompted with the palate insitu without visual feedback. He will be required to provide the correct production to a percentage correct of 100% (10/10 trials for each CVC structure).

**Aim 18**:
b) For AB to produce single words beginning or ending in a voiceless alveolar fricative or voiceless alveolar or velar stops.This will require alternating articulatory movements in regard to placement, and alterations in manner of articulation, in addition to varying vowel combinations. For AB to learn to produce the correct lingual-palatal consonant postures in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonants is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of C1VC2 structures where the C1 is either a voiceless alveolar fricative or voiceless alveolar or velar stop and C2 is the alternative of C1. AB will not have visual feedback but will have the palate insitu.

**Rating**: AB will be required to correctly produce the C1VC2 structures when prompted with the palate insitu without visual feedback. He will be required to provide the correct production to a percentage correct of 100% (10/10 trials for each CVC structure).

**Aim 18**:
c) For AB to produce single words beginning or ending in a voiceless alveolar fricative or voiceless alveolar or velar stop. This will require alternating articulatory movements in regard to placement, and alterations in manner of articulation, in addition to varying vowel combinations. For AB to learn to produce the correct lingual-palatal consonant postures in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonants is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of C1VC2 structures where the C1 is either a voiceless alveolar fricative or voiceless alveolar or velar stop and C2 is the alternative of C1. AB will not have visual feedback and will not have the palate insitu.

**Rating**: AB will be required to correctly produce the C1VC2 structures when prompted with the palate insitu without visual feedback. He will be required to provide the correct production to a percentage correct of 100% (10/10 trials for each CVC structure).

**Aim 19**:
a) For AB to produce single words beginning in a linguoalveolar stop and ending in an alveolar/velar stop or fricative. This will require alternating articulatory movements in regard to placement, and alterations in manner of articulation, in addition to varying vowel combinations. For AB to learn to produce the correct lingual-palatal consonant postures in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonants is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of C1VC2 structures where the C1 is either a voiceless alveolar fricative or voiceless alveolar or velar stop and C2 is the alternative of C1. AB will not have visual feedback but will have the palate insitu.

**Rating**: AB will be required to correctly produce the C1VC2 structures when prompted with the palate insitu without visual feedback. He will be required to provide the correct production to a percentage correct of 100% (10/10 trials for each CVC structure).

**Aim 19**:
b) For AB to produce single words beginning in a linguoalveolar stop and ending in an alveolar/velar stop or fricative. This will require alternating articulatory movements in regard to placement, and alterations in manner of articulation, in addition to varying vowel combinations. For AB to learn to produce the correct lingual-palatal consonant postures in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonants is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of C1VC2 structures where the C1 is either a voiceless alveolar fricative or voiceless alveolar or velar stop and C2 is the alternative of C1. AB will not have visual feedback but will have the palate insitu.

**Rating**: AB will be required to correctly produce the C1VC2 structures when prompted with the palate insitu without visual feedback. He will be required to provide the correct production to a percentage correct of 100% (10/10 trials for each CVC structure).

<u>Aim 19</u>:
c) For AB to produce single words beginning in a linguoalveolar stop and ending in an alveolar/velar stop or fricative. This will require alternating articulatory movements in regard to placement, and alterations in manner of articulation, in addition to varying vowel combinations. For AB to learn to produce the correct lingual-palatal consonant postures in combination with vowels. This skill is required to ensure the motor program for the lingual-palatal consonants is stabilised regardless of the phonetic environment.

**Activity**: AB will be required to produce a range of C1VC2 structures where the C1 is either a voiceless alveolar fricative or alveolar or velar stop and C2 is the alternative of C1. AB will not have visual feedback but will have the palate insitu.

**Rating**: AB will be required to correctly produce the C1VC2 structures when prompted without the palate insitu without visual feedback. He will be required to provide the correct production to a percentage correct of 100% (10/10 trials for each CVC structure).

<u>Aim 20.</u> **For AB to produce the phrase 'I take the' (with t and k in take to focus on stops) and complete the phrase using a variety of CVC combinations targeting his sounds in error:**
a) with the palate insitu with visual feedback
b) with the palate insitu without visual feedback
c) without the palate insitu and without visual feedback

<u>Aim 21.</u> **For AB to produce the phrase 'I saw the' (with s in saw to focus on fricatives) and complete the phrase using a variety of CVC combinations targeting** his sounds in error with the fricatives.
a) With the palate insitu with visual feedback with the palate insitu without visual feedback
b) With the palate insitu without visual feedback
c) Without the palate insitu without visual feedback with the palate insitu without visual feedback

<u>Aim 22.</u> **For AB to produce the phrase 'I cook the' (with k in cook to focus on velar stops) and complete the phrase using a variety of CVC combinations targeting his sounds in error with the fricatives.**
a) With the palate insitu with visual feedback
b) With the palate insitu without visual feedback
c) Without the palate insitu without visual feedback